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THE FAST NEUTRON HAZARD

Recent events have shown fast neutrons to be a considerable health hazard. Reported here are studies on how distribution of exposure time of 4-Mev neutrons, as compared with 185-kv X-rays, alters their effect on animals. Data from such experiments are not yet easily converted for the effect on humans

By TITUS C. EVANS

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BECAUSE they are uncharged, fast neutrons (1 to 4 Mev) are very penetrating. When it was demonstrated that the cyclotron could produce a neutron beam of high intensity, it became evident that these particles represented a new, potentially dangerous hazard (*1*).

Lead and other heavy materials, which are effective barriers for other high-energy radiations such as those encountered in ordinary laboratory uses of radioisotopes (*2*, *3*, *4*), allow considerable penetration of fast neutrons. Water, concrete and earth serve as better protective shields for neutrons because the particles lose energy rapidly in successive collisions with nuclei of hydrogenous materials.

Likewise, because of the physical properties of neutrons, ionization chambers designed for roentgen and gamma rays are not suited for absolute measurement of neutron radiation intensity. Several ionization chambers which can produce like readings of roentgen radiation may vary in hydrogen content, however; thus they will give different readings of the same beam of fast neutrons.

The Victoreen 100 r thimble chamber has been used in several laboratories to give relative readings of the neutron radiation intensity (*1*). The 100 r chamber and condenser r-meter has been a satisfactory means of measuring the neutron exposure in an arbitrary unit. In tissue, however, the amount of ionization produced by the two exposures (n) and (r) is not the same. The ratio of the "tissue r" to the "tissue n" has been approximated by devising "tissue-equivalent" chambers (*5*, *6*, *7*, *8*).

The results of these studies indicate that the r to n exposure ratio (based on the 100 r chamber) should be divided by 2 to 2.5 to approximate the relative tissue doses. In other words, 1 n = 2 to 2.5 rep (roentgen-equivalent-physical) or $\simeq$190 ergs per gm of tissue (*2*).

It was found in early biologic experiments (*1*, *9*, *10*) that, although the effects of neutrons and X-rays were similar, the action of the neutrons was greater even when the r/n exposures were divided by 2.5. In addition, data showed that neutrons selectively affected some tissues and organisms more than they did others (*1*, *11*, *12*, *13*, *14*, *15*). It was also found that the r/n ratio changed as the developmental and physiologic conditions changed within the same test object (*11*, *12*, *13*).

Zirkle (*16*), in his pioneer work, showed that, even with the same tissue-dose, the density of the ions along the paths of alpha particles altered the

amount of cellular damage produced. The greater biologic action of neutrons may be explained, at least in part, by the high specific ionization of recoil protons (and other recoil nuclei) produced in the tissue. The variation in relative sensitivity to neutrons of the different tissues and test objects may be related to the volume of the unit responsible for the observed effect. If one is studying gene changes, the sensitive volume is small, and densely ionizing particles are less effective per unit dose because some of the ions are "wasted." On the other hand, effects requiring absorption of several ions are more sensitive to neutrons or alpha particles, *etc.*

It is generally agreed that the biologic effect of ionizing radiations is related to the production of ion pairs because of their ability to initiate physical and chemical change. However, atoms may absorb enough energy to cause changes without ionization taking place. The proportion of the energy absorbed in excitation, for instance, to that absorbed in ionization may possibly vary from one type of radiation to another. It is also possible that effects on a biologic entity produced secondarily through action on neighboring molecules may be related to spatial distribution. A momentary concentration, above a critical level, here and there may be more effective than the same total of toxic molecules distributed generally so as to be of subcritical concentration in any one locus.

The possibility that human cancer might be especially susceptible to neutron radiation was explored by Stone and others (*17*). However, the cancercidal dose for neutrons was not sufficiently lower than that for harmful effects on normal tissues. Several interesting phenomena were observed. The relative biologic effectiveness in producing a threshold skin reaction was 1 n = 2.8 rep, but this ratio was not the same for all effects on the skin. It is quite evident that more information concerning effects of neutrons is to be desired at the present time since it *is* such a new and potentially dangerous hazard.

Even in the earliest phases of the Manhattan Project it was realized that much information was needed regarding the biologic effects of various radiations under different conditions of exposure. In recent years several AEC reports on the subject have been declassified, and the first volume of the *National Nuclear Energy Series* has just been announced as available (*18*). Some of the reports were released for presentation before scientific societies, and one of them is the basis for the experimental data which constitute the body of the present paper.*

Plan of the Experiments

The chief purpose of the investigation was to determine whether distribution of the exposure in time would alter the relative effectiveness of neutrons (*ca.* 4 Mev) as compared to X-rays (185 kv). The effects of the two types of radiation were determined under three conditions of exposure: (1) single acute, (2) multiple subacute, and (3) multiple very small or chronic. Because the same test object (laboratory mouse) and the same source of neutrons (36-inch Columbia cyclotron) were used throughout the investigation, it was not necessary to measure the dose in rep to observe changes in the neutron-X-ray exposure ratio. However, it is of interest to have the absolute values of the neutron doses and this is being

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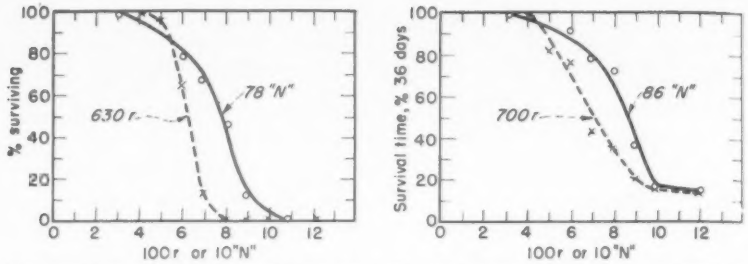
* "Effects of Small Daily Doses of Fast Neutrons on Mice," by T. C. Evans, *Radiology* **50**, 811–834 (1948). Presented at the Thirty-third Annual Meeting of the Radiological Society of North America, Boston, Mass., Nov. 30–Dec. 5, 1947. Based on work performed at the Radiological Research Laboratory, Columbia University, under contracts W7405-eng50 and W31-109-eng-14 for the Manhattan Project and the Atomic Energy Commission. MDDC-1450.



The number of animals surviving (in percentage of controls) 36 days after single radiation exposures

The mean survival time (in percentage of controls) plotted against the radiation exposure

FIG. 1. Relative effects of neutrons and X-rays in single exposures

determined in the Radiological Research Laboratory at Columbia University (*19*).

Single Acute Exposure

Mice were administered single exposures of X-rays ranging from 400 to 1200 r in increments of 100 r. Similar animals were treated with neutron exposures ranging from 30 to 150 "N" in increments of 10 "N." The "N" is an arbitrary unit of exposure based on the amount of ionization in a certain 25 r Victoreen thimble chamber equal to 1 r. The same chamber was used for determining the X-ray exposures in roentgens.

The effects on survival are shown in Fig. 1. The experiment was terminated 36 days after the irradiation. The number surviving at that time, in percentage of the control values, is shown in the left graph. The MLD (median lethal dose) was 630 r for X-rays and 78 "N" for the neutron radiation. Thus, for the MLD, r/"N" = *ca.*8. Likewise, as shown in the graph on the right, exposures necessary to reduce mean survival time (MST) to 50% of the control value were in the ratio r/"N" = *ca.* 8. The effects on the blood were similar in character, and the relative effects of neutrons and X-rays were consistent with an equivalence of 8 r and 1 "N."

Multiple Subacute Exposures

In this experiment four lots of fifty animals each were used. One of these was exposed to 80 r per day (6 days per week) and another lot was exposed to 10 "N" per day (6 days per week). The exposures were selected as being equivalent, according to the results of the acute exposure experiment. The other two lots were not irradiated. One of these made the daily trip to the cyclotron with those to be treated.

No difference in the two control lots was observed (*i.e.*, in survival, blood counts, *etc.*). The effect on survival is shown in Fig. 2.

The exposures were discontinued after the twenty-fifth day because over half of the original number of animals in the experimental lots had died. The median lethal time (MLT) for the entire roentgen-irradiated group was twenty-two days; for the neutron-treated lot the MLT was twenty-three days. The total white blood count dropped steadily from the first day after beginning the irradiations until the experiment was concluded on the twenty-fourth day. The red blood count and the hemoglobin content of

the blood remained within normal limits for about a week, and then dropped steadily as the irradiation continued. The slope of curves for the effects on the blood was approximately the same for the two kinds of radiation. Damage to the spleen, gonads, bone marrow, and intestinal lining was heavy especially toward the end of the irradiation period. As nearly as could be judged from the material, the injury produced by the two kinds of radiation was very similar.

Multiple Chronic Exposures

The effects of 11 r per day (5 days per week) were compared to those of 1.4 "N" per day (5 days per week) in three experiments.

In two experiments, the time to reduce survival to 50% (LT-50) of the original number was determined. For neutron exposures, the LT-50 was 183 days in one experiment, and 175 days in the other. For the roentgen-irradiated lots, the LT-50 was 275 days in the first experiment and 263 in the second. Likewise, the daily exposure of 1.4 "N" was much more effective than the treatment of 11 r per day in producing (1) damage to the lens of the eye, (2) injury to the reproductive organs, and (3) relative reduction in body weight. The effects on the blood and blood-forming organs did not show this greater susceptibility to the neutron radiation.

In the third experiment, animals were sacrificed at regular intervals to determine relative effects on the tissues. An additional daily exposure of 15 r was included. Histologic examination of the testis revealed greater damage with daily exposures of 1.4 "N" than with 11 r per day or even 15 r per day.

In the first two experiments (25 animals in each lot of experimentals and controls), the total dosage that had been administered at LT-50 was noted. These values of "N" were 175 and 158.

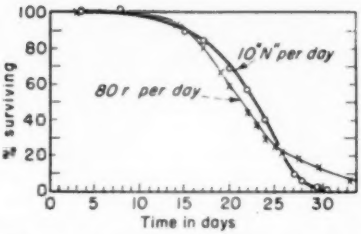


FIG. 2. Effect of 80 r per day and of 10 "N" per day on number surviving in percentage of the control value

For X-rays, it was 2,112 r in both experiments. The dosage for sterility in the males was 25 "N" and from 1,155 to 1,577 r. The dosage at the time estrous cycles were stopped in the females was 126 "N" and 1,760 r. In the one experiment comparing effects of 1.4 "N" per day, 11 r per day, and 15 r per day, the total dosage at the time mating tests had become negative was respectively 45 "N," 990 r, and 1,050 r.

Very Small Daily Neutron Exposures

The five groups of animals (100 each) used in these experiments were treated daily (5 times per week) as follows: controls, 0.014 "N," 0.07 "N," 0.14 "N," and 1.4 "N." The exposures were continued until the survivors, even in the control group, were reduced to less than half of the original number. The mean (and standard error of the mean) survival times were as follows: controls = 62 $\pm$ 2.2 wk, 0.014 "N" = 62 $\pm$ 1.6 wk, 0.07 "N" = 60.6 $\pm$ 2.0 wk, 0.14 "N" = 54 $\pm$ 2.0 wk, and 1.4 "N" = 26.6 $\pm$ 0.96 wk.

The survival time in percentage of controls is shown in Fig. 3. Effects of 10 "N" per day have been included to show a more complete curve. The lowest daily exposure which significantly reduced the MST was 0.14 "N." However, the frequency of animals living longer than 500 days

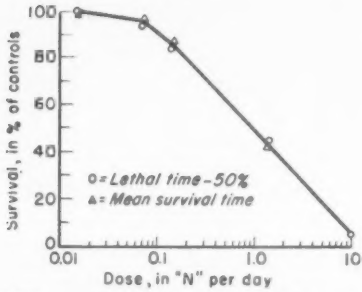


FIG. 3. Survival, expressed in percentage of control, at different daily levels of exposure, and indicated by both the mean survival time and the time required to reduce the number to 50% of that at the beginning of the experiment

was only 30% in the 0.07 "N" per day group, whereas in the 0.014 "N" per day group and in the controls it was from 38 to 41%.

The only progressive injury to the blood was in the 1.4 "N" per day group. This was primarily a reduction in the number of white blood cells (especially lymphocytes). The mean white blood cell count of the other irradiated lots was usually slightly lower than in the controls but even this slight effect did not become more pronounced as the experiment progressed. This slight reduction in mean white blood count was accounted for by a slight reduction in the frequency of counts which were high but within normal limits (15,000–30,000). In the controls, this group occurred with a frequency of 35%, in the 0.014 "N" group it was *ca.* 22%, in the 0.07 "N" group it was 18%, in the 0.14 "N" group it was 13%, and in the 01.4 "N" group it was about 10%.

The spleen is a very radiosensitive organ, and some evidence of injury was found in animals receiving daily exposures of as little as 0.14 "N." In fact, there was some indication that unusually active (from a growth standpoint) spleens were affected by exposures as low as 0.07 "N" per day.

The lens was extremely sensitive to accumulated effects of small daily exposures, although the cataracts developed very slowly. Examination with the slit lamp revealed damage (as compared to controls) in 32% of the animals in the 0.07 "N" group, in 85% of those of the 0.14 "N" lot and in all of those exposed to 1.4 "N" per day who lived beyond the LT-50.

Effects on the reproductive organs were found in the group exposed to 0.14 "N" per day, and in the 1.4 "N" per day lot the injury was pronounced.

There was no definite indication of an increase in the frequency of tumors in the irradiated animals but the design of the experiment did not provide optimal conditions for this possible radiation effect.

In a repeat experiment with exposure of 1.4 "N" per day, black mice were employed, and by LT-50 there was considerable evidence of epilation and depigmentation of the surviving hair in the irradiated animals.

Discussion

The r to "N" ratio appeared to increase as the magnitude of the daily exposures was decreased. The ratio of r/"N" = 8 which held for single acute exposures, and for daily treatments of 80 r or 10 "N," did not hold for daily exposures of 11 r or 1.4 "N." In one experiment to test this ratio of effectiveness, the total dosage at LT-50 was in the ratio r/"N" = 12.1 and in another it was r/"N" = 13.3 r. If percentage reduction in survival time is used, the value for 11 r per day = 40. By interpolating between the points on the curve of Fig. 3, a 40% reduction in survival time would be expected from daily exposures of 0.62 "N." This would give a ratio of r/"N" = 18. Henshaw, *et al.* (*19*) using this method found that the effect of 8.6 r/day was equal to what would be expected of 0.25 n/day to give the ratio r/n = 35.

In our experiments, daily exposures of 0.14 "N" reduced survival by about 15%. In experiments by Lorenz, *et al.* (*20*), survival was reduced by this amount in mice exposed daily to 4.4 r of gamma radiation.

A comparison of results of experiments with different strains of mice, *etc.*, is valid only in a very general way, but it is interesting that the equivalence obtained (1 "N" or n = 31.4 r) does agree with the value suggested by Henshaw, *et al.* (*19*) for 8.6 r per day and 0.26 n per day. There was good agreement between experiments of Henshaw, *et al.*, (*19*) and Lorenz, *et al.* (*20*) as 8.6 r per day reduced survival by approximately 22% in one investigation and in the other one 8.8 r per day reduced survival times by approximately 26%.

It may well be that the equivalence of r and n in the so-called "tolerance range" is as high as 30, or, if the factor of 2.5 is correct for these radiations, 1 "N" or n = 12 rep. Even for single exposures, Henshaw, *et al.* (*19*) and Mitchell (*8*) found that reducing the intensity of the radiations increased the r to n ratio.

The conclusion that the r to "N" ratio increases as the intensity of the exposures decreases should not be accepted without reservation because evidence is meager as yet. However, an explanation for the phenomenon is apparently at hand. Marshak (*12, 13*), Gray (*21, 22*), and Spear (*23*) obtained evidence that the effects of X-rays and gamma rays are more selectively restricted to mitotically active cells whereas neutrons affect cells in all stages. It may be that effects of neutrons persist longer than those of X-rays and gamma rays so that some tissues are selectively damaged by neutrons.

In our experiments, the effect of 1.4 "N" per day on the lens was so much greater than the effect of 11 r per day that an evaluation of the r/"N" ratio for this effect could not be estimated. The lens has been found to be especially sensitive to neutrons in experiments with vertebrates other than mammals (*24*).

The testis also appears to be selectively injured by neutron radiation. Effects on mating tests indicated, roughly, a ratio of r/"N" = 34 based on total dosage at the time such tests became negative. Histologic studies of the testes after irradiation indicated that the effect of 1.4 "N" per day was at least greater than that of 15 r per day. Although there was some variation, the other tissues studied appeared to be affected in somewhat the same ratio of exposures as obtained for the reduction in life.

Differential susceptibility of spermatogenesis to neutrons (in single exposures) as compared to X-rays has been reported (*25*) and indeed differences in the relative effects of neutrons and X-rays on closely related tissues has been a general finding (*1, 11, 15*). Stone (*17*) concluded, from the work on patients with the California cyclotrons, that 1 rep of neutrons was equal in effect to 2.5 r of X-rays for a threshold erythema reaction, but for the late reactions it might be as high as 4 r.

Additional evidence that injury from neutrons may be due to mechanisms different from those of gamma-ray reactions has been presented by Mitchell (*8*). Mixtures of neutron and gamma radiation were not additive in their effects. It should be mentioned, however, that complete additivity of neutron exposures and gamma-ray treatments has been reported (*26*).

Although our experiments did not give much information regarding tumor production, there is evidence from other investigations (*19, 20, 27, 28*) that neutron exposures may increase the frequency of tumor formation. Relative efficiencies of n and r for this effect

have not been clearly determined at the present time.

Many problems remain and it is difficult to transfer information from animal experiments for use in setting of a daily permissible exposure for man. Some evaluations have been made from limited experience with neutron therapy (*17*), atom bomb casualties (*29*), and general considerations (*30*).

An equivalence of 1 n = 10 r has been accepted as a temporary working basis for permissible exposures. Thus, the daily acceptable dose is 0.01 n, which corresponds to 0.02 rep and a flux of approximately 200 fast neutrons per cm^2 per second for eight hours (*31*, *32*).

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IN THE OPERATION of radiochemical facilities, two degrees of freedom, manipulative and procedural, are at least partially lost, owing to the contamination and radiation parameters. Below 1 millicurie, this need reflect only minor changes in existing laboratory design, but major changes in existing laboratory practice. Above 1 millicurie, one must specify more rigidly not only what kind and how much activity will be met, but the methods by which the work will be conducted. The laboratory may then be designed to meet these limits, leaving for special consideration problems that fall outside the specifications.
—P. C. Tompkins, H. A. Levy, Ind. Eng. Chem. **41,** *231 (1949)*

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WASTE DISPOSAL SYMPOSIUM

AT A TWO-DAY SEMINAR in Washington, January 24–25, representatives of the sanitary and waterworks engineering associations met with the representatives of the Atomic Energy Commission and other government departments to discuss the general problems of disposal of atomic wastes. A review of the material presented at this meeting follows.

For the Commission the following individuals made statements and answered questions from those in attendance:

David E. Lilienthal, chairman, Atomic Energy Commission

Dr. Shields Warren, director, Division of Biology and Medicine, AEC

Dr. Austin Brues, director, Division of Biology and Medicine, Argonne National Laboratory, Chicago

Arthur V. Peterson, associate director, Division of Production, AEC

Roger S. Warner, director, Division of Engineering, AEC

Dr. Paul Aebersold, director, Isotopes Division, AEC, Oak Ridge

Dr. Karl Z. Morgan, director, Health Physics Branch, Oak Ridge National Laboratory

W. A. Rodger, Chemical Engineering Division, Argonne National Laboratory, Chicago

Arthur E. Gorman, Division of Engineering, AEC

C. C. Ruchhoft, Environmental Health Center, U. S. Public Health Service, Cincinnati

Dr. Abel Wolman, head, Department of Sanitary Engineering, Johns Hopkins University, and consultant to AEC

In addition to representatives from government departments, the participants in the seminar were selected from membership of the American Water Works Association, Federation of Sewage Works Associations, Conference of State Sanitary Engineers, and Conference of Municipal Sanitary Engineers. In addition to AEC, the following government agencies took part in the discussions: U. S. Public Health Service, the U. S. Geological Survey, the U. S. Weather Bureau, the Tennessee Valley Authority, the Office of the Secretary of Defense and the Department of Navy.

In this report, the several talks by the AEC representatives and the answers to questions raised by the seminar participants are integrated and to conserve space the responsibility for the statements reported is not always indicated here.

The general subject matter of the discussions concerned the types of radiation produced in atomic energy activities; the effects, controls, tolerances and methods of measuring radioactivity; the production, distribution, use and controls of radioisotopes; health problems; current methods of disposal of gaseous, liquid and solid radioactive wastes; and an appraisal of the sanitary engineering problems in the atomic energy industry.

Sources and Types of Radiation

All the problems with which the sanitary and waterworks engineer must deal in connection with atomic energy are caused by the simple fact that atoms break down in the several processes concerned, that when these atoms break apart certain particles or radiations are given off; that these radiations may be highly penetrating and damaging to living tissue; and that some of these radiations have long lives.

There is nothing new in the fact that plants and animals live in a sea of

radiation. For example those who live in Baltimore or New York will get in the course of their lives about 2 r of cosmic rays,* those living in the mountainous regions in the West will get about 10 times this amount. Many people are exposed at one time or another to the effects of X-rays or radium. What is new about the atomic energy situation is the vast quantities of radiation involved. Within the United States there are perhaps 30 ounces of radium but within the pile at Oak Ridge there are radioactive substances the equivalent of tons of radium.

Naturally the greatest source of wastes which must be disposed result from pile operation but certain problems arise even when small-scale activities involving nuclear reactions occur, in research into the effects of radiation on living matter, for example.

Radioactive wastes, like chemically toxic wastes, originate in the vast production operations, in the pilot plants and in the laboratories. An engineer must worry not only about safe routine operations, but also the difficulties of maintenance, handling of spills, and the series of circumstances which when coupled together create a major unforeseen contingency.

Most of the operations of ore dressing and feed preparations are not associated with any great quantities of radiation. The largest and the most difficult problems are those directly associated with or resulting from nuclear reactor operations, where the degree of radioactivity is enormous.

The process of fission creates considerable quantities of heat which must be dissipated. In the case of Hanford, reactors are cooled by water: those at Oak Ridge and Brookhaven are cooled by air. Both methods of cooling involve open cycles without the re-use of coolant. Other coolants will undoubtedly be developed in the future which will involve higher temperatures and closed cycles.

At Hanford, the water is drawn from the Columbia River, treated in the normal manner, pumped through the pile at high velocities, held in a retention basin to permit the decay of such radiation picked up by the soluble salts and then discharged into the river. The exit temperatures may be several degrees above river water but the temperature of the river is not noticeably changed. Actually under normal operating conditions the chemicals in the water offer more of a hazard than the radiation. The aluminum cartridge which holds the uranium fuel slug may rupture on occasion and water may become contaminated above acceptable levels; but in event this happens the water is diverted prior to discharge into the river.

At Oak Ridge, and shortly at Brookhaven, air for cooling reactors is filtered for particles before and after use and then discharged into the air through stacks. Argon and other rare gases contained in normal air become radioactive, but the half-life of radioargon is slightly less than two hours and the volumes are low. Meteorological control of the operation is maintained so that dilution by wind is assured. If the wind is wrong the operations rate is reduced.

Slugs containing uranium, plutonium and fission products ejected from the pile are allowed to "cool" to permit the decay of a large amount of the short life activity such as iodine.

These slugs are then removed for chemical processing to recover the plutonium. They pass through conventional steps of dissolving, precipitating, washing and re-precipitating —operations which are conducted by remote control behind many feet of

* The Roentgen (r) is the unit of energy absorbed by air. One Roentgen equals 83.8 ergs per gram of dry air. It is used specifically to measure X-rays and gamma radiation.

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concrete and using special ventilation. Ventilating air contaminated with particles from this process passes through scrub traps, sand filters and out a stack, again under controlled meteorological conditions.

The liquids increase in volume and hence the radioactivity is reduced from step to step. Ultimately the most radioactive wastes are neutralized and stored in tanks underground. Concentration of these large volumes has not been perfected as yet. Wash wastes are also tanked but after a sufficient period of decay are discharged. This practice was adopted during the war, but it is gradually being superseded as fast as better methods are developed. Before long we can say with assurance that the liquids are completely immobilized and under positive control.

Considerable quantities of contaminated clothing are laundered and tested for re-use. Contaminated trash, biological specimens, etc., are disposed of by burial and more recently in closed-cycle incinerators in some areas. Contaminated equipment such as motors, valves, piping is set aside in a burial area. Lead and more recently aluminum shielding blocks used in pilot plant work have been decontaminated for re-issue. Considerable quantities of contaminated metals of one type or another have been segregated and some effort has been spent to see whether they could be decontaminated satisfactorily enough to put back into commerce. To date such accumulations have remained on Commission sites even though the level of activity is quite low. Contaminated buildings present a problem. After some attempt at decontamination the buildings are usually painted, taken apart board by board and stored in a burial area. Large incinerators with a closed combustion cycle are in design but their feasibility has not yet been established.

In "hot" laboratories, handling of liquid wastes and ventilation is done in various ways with some degree of success. No single method stands out for general use. Users of isotopes in tracer work do not as yet run into particularly severe waste problems, because of the low degree of activity.

In brief, gaseous, liquid and solid wastes appear at each of the various hot steps. The expedients for disposal used to date have at least stood the test of time. The ultimate goal is improvements in the basic design at the source of the waste rather than attempting to deal with the wastes after they have been produced by such means as filters, and retention basins. These steps will still be necessary, but they will be superseded as the first line of defense. The storage of hot liquid wastes is expensive. It can be endured for a time at one or two locations, but if the industry is to expand as we contemplate, we will ultimately need better means of isolation, concentration, immobilization and control.

General Tolerance to Radiation

Experience with X-rays and radium has shown that, if a group of people were given a single dose of gamma radiation of 450 r, about half of the group would die. However, most individuals could take 450 r if it were given not in a single dose but in a series of small doses over a period of several months. A diagnostic chest X-ray is equivalent to about 10 r. Experience reveals that most individuals can withstand a daily dose of 1 r indefinitely without apparent injury. In setting a permissible limit, doctors incorporate a factor of safety of about 10; hence, 0.1 r per day is the standard permissible limit for continuous exposure. This applies to persons working in atomic energy installations and physicians and nurses working with X-rays. All types of radiation—alpha, beta, X-rays,

gamma rays as from radium, or neutrons—act qualitatively in the same way. There are quantitative differences between them. There are differences in powers of penetration. But, from the standpoint of injury done to tissue, the injury done by one type of ionizing radiation is virtually the same as that done by another type.

There is a tremendous difference between the amount of radiation a person can take in the body as a whole and what he can take in a small part of his body. That helps reduce the danger from the absorption externally of most radioactive materials, because a good share of them tend to be concentrated in one or another of the body tissues.

On a field ½-inch square, a dose of 5,000 r is not infrequently used to cure a small skin cancer. A scar will persist, but no harm is done. A tenth of that total given to the whole individual, would be enough to kill.

What the human body will stand in the way of radiation is known: 100 r will do some, although very slight, harm; the least dose with which evidence of harm can be constantly detected in humans is about 15 r; 0.1 r repeated day in and day out has not done harm. People working daily with large amounts of ionizing radiations need not receive even this permissible dose or even half of it except at rare intervals if they obey the rules which have been worked out.

Other living organisms, however, have different tolerances. Dr. Warren noted that he had radiated cultures of bacteria with upwards of 200,000 r and had found them resistant. Viruses take well up into hundreds of thousands of r to have any effect upon them. If a population of paramecium is radiated with about 300,000 r, half would die. In the pupal stage of some insects, the dose required to kill half (known as the LD-50 dose) is about 150,000 r. In the rat the LD-50 runs between 825 and 900 r; in the guinea pig, however, the dose to kill half of a population is only 250 r. Plants in general are far more resistant than animals.

The fact that animals have the ability to concentrate specific materials in certain parts of their system is a point that is important. The oyster, for instance, separates out calcium with which to build its shell which may weigh as much as 8 times as much as the oyster. These biologic concentrations of waste materials have caused some degree of concern as to whether it might be conceivable, first to have concentration in algae, then in snails that live on the algae, then in fish that eat the snails—whether we could wind up with a concentration that would be dangerous to humans. Although much further research must be undertaken before the full story of this situation will be learned, work to date indicates that such concentration will not be dangerous. For example, the deleterious products are stored, not in the part of the fish that is eaten, but largely in the skeleton. In the fish at Bikini which had opportunity to get large amounts of fission products from the underwater blast, there was relatively little activity in the fish flesh as compared to the bones.

Exposure to radioactivity may be incurred not only from external sources but by taking into the body materials which are radioactive.

Internal radiation hinges on several factors. The amount and character depend first on the quantity absorbed. One of the very dangerous radioactive substances is plutonium, but if plutonium is swallowed only a very small fraction ever gets into the body. The bulk is insoluble and is not absorbed.

Secondly, the quality of the radiation, whether the particular material taken in is an alpha, a beta or a gamma emitter, or even in very rare instances

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an emitter of neutrons, is important.

Third, the point where the material goes is very important. Sodium diffuses widely throughout the body. If a small amount of radioactive sodium is swallowed, it will be distributed widely throughout the body so that a gram of deltoid muscle will contain about as much as a gram of lung or spleen. On the other hand, iodine is absorbed in highly selective fashion and roughly seven-eighths of the iodine that is absorbed in the body winds up in the thyroid gland. In a 150-pound man, the thyroid will probably weigh 15 to 18 grams. There is not only a concentration by virtue of the seven-eighths localized there, but a further concentration by virtue of the great disparity in size between the thyroid and the body as a whole.

A fourth factor of importance is the rate of excretion from the body. Sodium leaves almost as fast as it enters. Some of the fission products, radioactive strontium and plutonium, are deposited in bones and may remain there for a considerable period of time.

Fifth, the half-life of the material counts a great deal. A material such as fluorine, with 118 minutes of half-life cannot be, in any ordinary quantities, a serious radiation hazard. Radioactive carbon on the contrary may be present in minute amounts and even though its radiation is very soft, the fact that its half-life is 5,100 years means that the material maintains its full potency for as long as an individual lives and as long as any of the material remains within him.

To sum up the situation then, so far as external ionizing radiation is concerned, there is no hazard with proper methods of disposal; that from the standpoint of internal radiation, to the best of our knowledge, the precautions we are utilizing are given adequate protection. The matter of concentration has to be worked out further, although the indications are that we are as yet within safe limits. We are striving for as near the ideal as possible; we would like to get as near zero output of radioactivity as we can attain. We have measuring devices that can detect activity at a level that will not be dangerous to humans. We have a means of knowing what our hazard is and of measuring that hazard.

On the general subject of tolerance, Dr. Austin Brues made the following contribution:

Some recent work has shown that in certain rather specific cases, such as the increase in size of the ovaries in mice given small amounts of radiation, detectable effects occasionally occur at 0.5 r per day. Also, animal experiments have shown that 1 r per day in an animal may have possible effects on the life span.

In the case of absorbed internal emitters we have better means of comparison between experimental work and the human instance than we have in the case of external radiation. A number of individuals have suffered late effects of the absorption of radium, particularly workers in the radium industry. At any rate, we have data indicating how much radium is in the skeleton of a person who has suffered from these changes ten or twenty years after the time of exposure and we also have data on the amount of radium which may commonly be found in the skeleton of individuals who do not show any such changes. About 1 microgram of radium retained in the skeleton does, in a fair proportion of cases, produce degenerative changes in bones and latent bone tumors may occur. This gives something very definite to tie to in the case of other radioelements.

In experimental work on animals considerably higher concentrations of radium in the bone are necessary to induce tumors in rats or mice or rabbits. The factor is possibly 100, and for this

reason it is fortunate that we have the data for humans. A probable reason for the difference is that radium is much more effective after a matter of decades than it is after a matter of years, and the life-span of animals is not measured in decades.

In deriving these tolerance values, we not only have a ceiling, which is the amount we know will produce deleterious effects, but we also have a floor, representing the normal amount of radioactivity present in an individual under natural environmental conditions. At least four radioactive materials are normally found in the human body, carbon-14, potassium-41, radium, and uranium.

There are two aspects to the question of the relation between radiation and health. On the negative side we have the fact that late and remote effects can be produced by radiations, either by continuous low-level external radiation or by internally absorbed materials, and that these may occur under conditions where no physical defects are noted at the time of exposure.

Radioisotopes, Production, Distribution, Use and Control

Dr. Aebersold contributed the following remarks and discussion dealing with the general subject of radioisotopes.

The amount of radioisotopes distributed outside the AEC is very small compared with the amounts produced or needed to be disposed of within. In order of magnitude there is a difference of many millions.

Most of the distributed radioisotopes have fairly short half-lives or are elements which are not specifically concentrated in a human body at dilutions encountered after the experiment.

Considerable dilution occurs in all tracer experiments and also in most medical experiments, because of the incorporation of material into such a large organism as the human being. There is also subsequent disposal into sewage, resulting in dilution with large amount of organic matter.

There are as yet no large-scale uses in commercial processes, or in any process in which material is incorporated into a product distributed to the public. Also, there are no such amounts used in any industrial process that a large affluence into a sewage system would result. Most of the uses in commercial plants are for tracer research work.

Lists of institutions receiving isotopes during the month are now sent out monthly to public health officers and to state health officers. It is planned to hold informative discussions with such health officers to discuss with them the ways these isotopes are used and the necessary measures to be taken to prevent their unsafe disposal. For example, citric acid, peroxide and permanganese are used as decontaminating agents for clothing, the hands, etc., but once the radioactive materials are out of the clothing and off the hands, the liquid must be disposed of.

Points which came up in the discussion of Dr. Aebersold's remarks were:

The radioactive material in water behaves exactly the same as stable materials in water. There are certain elements such as radioactive tellurium which are dissolved in the water and stay there; they are not taken out by mud. Most of the materials, however, are taken out rather quickly by mud and plant life in a stream.

In the case of ground water supplies, the question was asked if water came into contact with carbon-14 in the form of insoluble carbonate or barium carbonate, would the dissolved material in the water pick up the carbon-14 compound and carry it on? The answer was that if the material was insoluble, it would probably not travel very far. As the water passes through the soil, the radioactivity would be held and would not pass very far.

Another useful point was the fact that one cannot get rid of radioactivity by any chemical means or even any physical means. When a thing is made radioactive, a certain number of radioactive atoms are made; there is no way in which this radioactivity can be canceled. Either you wait for it to die away, or, if it does not die away, you have to exclude it some place, or else dilute it.

A second point is that the only way of making radioactive material is by bombardment with neutrons or heavily charged particles. Consequently, just coming near radioactive material will not produce radioactivity.

Another question was this: If a ton of carcasses from some biologic laboratory using carbon-14 in its experiments is sent to be burned in an incinerator, is it true there would be no problem because it is being burned in plenty of dilution? Also will the ashes be free of radioactive materials?

The answer was that a closed-cycle incinerator was being developed which would absorb the radioactivity instead of putting it in the air. The people who do the incineration now usually level back the ashes, mix them with dirt and concrete and bury them at a depth so that they are well diluted.

Professor Rolf Eliassen, New York University, pointed out that radiocarbon was used very little because of its long life, but that iodine and phosphorus were different matters. He said: We are using phosphorus-32 in New York and if all the phosphorus-32 and all the radioiodine were dumped into the sewer, with full strength of activity, the dilution of a billion gallons a day of sewage would give a concentration of 3×10^{-8} microcurie* per cc, or about the order of magnitude of the water supply at Oak Ridge.

Phosphorus-32 loses half of its activity, every two weeks or so, and the danger in view of the dilution in the sewage is not very great at the present stage of activity in the various hospitals around the city. The danger is concentration in plumbing fixtures, e.g. in the slimes of these fixtures or other places.

On reply Dr. Aebersold said: Our health rules call for the user's surveying any plumbing fixture before any plumber is called in to work with them. If there is any activity in the slime it should be removed or else the plumber should wear rubber gloves.

Tolerance levels are set for people who work with radioactivity or who may be exposed to it continuously. In the case of the plumber who comes in and works on it once every six months or once a year, we set the same tolerance, but the man is protected by a factor of several hundred or thousand by the fact that he does not do this all the time.

Radioactive iodine and radioactive phosphorous are the only ones that are used in large quantities for treatment. Suppose somebody should come along and find a treatment for a widespread disease that was very successful with carbon-14 (not now forseen). Before it ever went into commercial production or was used by the general field of medicine, our advisory committees on this subject, the Isotope Advisory Committee, and the one on Industrial Processing and Waste Disposal, would have to give it very serious consideration. It may be in time, if there is any large scale use of fission products, that those wastes may have to be returned to Commission laboratories. A similar situation might arise with some isotopes. This may not be true of phosphorus and iodine, because they would be decayed before they would get back. In the case of carbon-14, it would depend on how large the program might be. None

* A microcurie represents 37 thousand radioactive disintegrations per second.

of the other isotopes present serious problems except for fission products.

General Remarks on Waste Disposal

As a preamble to discussions of the disposal of specific types of waste products, Dr. Karl Z. Morgan gave useful information regarding the activity at Oak Ridge.

An air-cooled pile, such as the one at Oak Ridge, induces activity into the cooling air and in any dust contained in the cooling air stream. Radioargon is the principal radioisotope discharged into the air. Since it is not selectively absorbed in the body it presents a minimum hazard and is disposed of from tall stacks which give an adequate dilution factor. The radioactive dust is removed by the use of filters. Continuous air samples and other measurements are taken in the neighborhood of the pile building to insure that its operation is maintained safely at all times. Some of the instruments in use to monitor the air activity at Oak Ridge are as follows:

1. Geiger counters suspended in the air at various stations to measure the activity of radioactive gas, such as radioargon, radioiodine and radioxenon.
2. Geiger counters used as described above, but with a filter paper about them through which air is drawn continuously and upon which the radioactive dust particles may collect.
3. Precipitators from which foils are removed at regular intervals and counted for alpha, beta and gamma activity.
4. Large ion condenser chambers are charged every eight hours and the amount of discharge is read with the aid of a fiber electrometer.
5. The air way filter, a very useful air sampling instrument, draws air at the rate of about 60 cubic feet per minute. The paper filter is removed after each run, counted with a Geiger counter and placed on a large film for 24 hours. The general blackening and any black spots on the film are a measure of the particulate radioactive material collected from the air. Other filter collectors in use are the continuous air monitor and a large U.S.P.H.S. filter which draws air at the rate of 240 cubic feet per minute.
6. Collecting frames are placed all over the area in the neighborhood of the pile. The dust that settles on these frames is placed on films for examination of film blackening at regular intervals.

The most successful method of control of contamination occasioned by chemical operations is to confine the contamination as much as possible and remove the contaminants from the smallest possible volumes of air (or water) near the source. One method of contamination control that offers considerable promise for certain operations is isotopic dilution. If radioactive carbon dioxide is being discharged up a stack, perhaps the safest method of rendering the contaminant safe is to dilute it sufficiently with ordinary carbon dioxide. However, if such a method is used, good mixing with the same chemical and physical form of inert material must be obtained in order that the radioactive contaminant be diluted to a safe level.

The chemical liquid waste has always presented a very difficult problem. Most of the fission product liquid waste has no present use and is stored in underground tanks and allowed to decay. At Oak Ridge, it passes into a large holding pond and from here it goes into White Oak Lake. The entire waste system is in the Oak Ridge restricted area and very careful measurements are made of the general level of radioactivity of the waste and its

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chemical composition before it is permitted to leave the area of control. It has been calculated that five curies per day of mixed fission products can be discharged safely into this lake system and this level has been maintained by constant measurements with various types of instruments. The three criteria of safe operation of the liquid waste disposal system at Oak Ridge are as follows:

1. The average discharge of mixed fission products into White Oak Creek must not exceed 5 curies per day and in no case may it exceed 35 curies per week.
2. The total radiation level in the water must not exceed 100 millireps per day, which is considered to be the maximum permissible level of radiation exposure.
3. The concentration of any one or any combination of radioisotopes in the lake water must not exceed the maximum permissible concentration that is calculated on the basis of what could concentrate in any body organ during the lifetime of the fish or of a man using this water from White Oak Lake as the sole source of water. In addition to this, there is a dilution factor of from 20 to 1000 when the water at White Oak Lake enters Clinch River, which brings the contamination level many times below what has been calculated to be a safe concentration.

The National Radiation Protection Committee of the National Bureau of Standards is responsible for setting standards and the AEC operations will maintain all the standards set by this organization. One section of the Oak Ridge Health Physics Division is compiling data on maximum permissible concentrations of the various radioactive materials and is striving to issue a preliminary report for this committee some time during the latter part of this year. At present it seems likely that the recommended concentrations of general mixtures of radioactive materials, when the elements or chemical form of these elements present *is not known*, will be the values shown in the table below.

The permissible concentrations in water have all been calculated for a considerable number of radioactive fission products. Safety factors of 10 to 100 are added to these calculated values to take care of non-uniform mixing or streaming of these radioactive materials after they are discharged into a river system. Also, biological, physical and chemical factors may tend to concentrate certain of these radioisotopes downstream and some factor of safety is added to provide a measure of added protection.

The algae in the settling pond and the clay and vegetation in the White Oak Lake system have a varied efficiency from time to time in the effective radioactive hold-up. Surveys are made of the mud activity in White Oak Lake from time to time. On the average,

Probable Maximum Permissible Concentrations of General Radioactive Contaminants Beyond the Area of Control

Kind of Exposure in	*Maximum Permissible Concentration in μc/cc for*	
	Beta or Gamma emitter	*Alpha emitter*
Air	10^{-9}	5×10^{-12}
Water	10^{-7}	10^{-7}

about half as much activity is discharged from White Oak Lake as enters it. However, the average decay is such that about only one fourth of this year's cumulative activity remains at the close of the year.

During the year 1948 the probable average concentration of beta activity in the Clinch River due to Oak Ridge operations was about 10^{-7} microcurie per cc.

The general beta and gamma background outside the Oak Ridge plant area has not exceeded twice natural background. In other words, the radiation contributed by Oak Ridge to the surrounding area is less than the added cosmic radiation exposure one receives in going from sea level to 5,000 feet elevation.

The maximum water activity in Clinch River of 5×10^{-7} microcurie per cubic centimeter seems to be safe. We may compare it with the radon activity in some American mineral springs, the water of which is prized for human consumption. Water taken from such springs in Colorado, Indiana, Missouri, Ohio, New York, Texas and Virginia has been tested and in every case the radioactivity content is as high or higher than that of the Clinch River. Moreover, the activity at Oak Ridge is primarily beta and gamma. The alpha activity is negligible. Radon is an alpha emitter, and in general alpha emitters are about 10 times more hazardous when taken into the body than beta and gamma emitters. This may mean an added factor of safety.

Liquid Waste Disposal

W. A. Rodger, Argonne, had the following to say about the general subject of liquid waste disposal.

Liquid wastes are produced in some quantity whenever radioactive materials are processed; e.g., the bench drains and wash-up sinks of a radiochemical laboratory. Since it is the practice to collect all known active wastes in special containers, activity which gets into the laboratory drainage system is at a very low level, in the order of a few millicuries per month. The composition of such waste may vary from time to time; it will be fixed with a relatively large volume of water; and it will generally be low in salt content. Any treatment system devised must obviously be flexible.

In pilot plant operations and in production plants the waste disposal problems encountered in the laboratory are scaled up so that much larger amounts of active wastes are produced. Amount and type will vary with the operation. For any particular process, however, a waste of known composition will be produced routinely. Concentration of radioactivity may be very high and the amounts of inactive salts may run up to 40 or 50%. Such wastes are more difficult to handle as heavily shielded equipment may be needed, but because the feed composition is known, specific treatment processes can be devised and equipment selected to carry out the necessary operations.

Types of Waste Producers. Work done at hospitals, universities, industrial laboratories and other non-AEC facilities usually involves the use of only very small quantities of radioactive tracers.

At Argonne, Brookhaven and Knolls Atomic Power Laboratory, somewhat larger quantities of radioactive wastes may be expected. All of these sites are building facilities which may be used as interim processing units and which will allow research and development to be carried out to determine ultimate systems. In the meantime, wastes are collected in suitable containers and shipped to sites with disposal facilities.

At Oak Ridge, a pilot plant is operated in addition to a research unit. Here activities in the order of kilocuries

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per month are processed and the total volume of waste may reach 50,000 gallons per week. The waste disposal system consists of a series of holdup tanks and a retention pond of over 1,000,000 gallons capacity. Uranium bearing wastes are segregated and stored indefinitely. Other wastes are held up, flocculated, and settled in a series of tanks. The supernatant is discharged to the retention tank where it is diluted with large volumes of water and discharged to the Tennessee Valley water system at concentrations no greater than 1 microcurie per liter. This is an example of discharge of activity back to nature after dilution sufficient so that no damage is contemplated.

The plutonium production plant at Richland, Washington, produces the largest volume of waste and the greatest quantity of radioactivity found at any site. The waste disposal system at Hanford resembles the one at Oak Ridge, but it is much more extensive. Uranium-bearing wastes and the most active nonmetal wastes are stored indefinitely. Less active wastes are held up and disposed of by other means.

There is a thick layer of volcanic ash in this area which absorbs activity very completely and so far has been successful in holding the activity close to the discharge point. This is an example of discharge to nature in such a way that the activity is confined. The solution appears indigenous to Hanford.

Much work has been started on developing methods which will allow the return to nature of the water, while retaining essentially all of the activity. One method which seems certain of success but which may be laborious and expensive is evaporation. Work so far has shown that a decontamination factor of at least 100,000 is possible. For many wastes, this is adequate. For others, a retreatment of the distillate might be required.

The use of ion exchange resins is also under study. Many possible processes will be tried. For instance the distillate from a single evaporation might be put through a resin column to assure removal of the last trace of activity. Rather than re-use the resin, it may be desirable to dry and incinerate it ending up with only a small volume of active ash to be stored.

Various chemical precipitation methods will be investigated. These will probably work best on specific waste streams from routine processing.

Certain of the present waste streams contain high concentrations of nonactive salts which may be recoverable for re-use. This is desirable from two standpoints. It would represent an economic saving and would make unnecessary the storage of the bulk solid. One such scheme now under consideration involves precipitation of the salt with 100% NHO_3, separation of the solid, and recovery of the acid by distillation.

Most of this work is in the very preliminary stage, but early indications is that much of it will be successful.

Goals. The aim of the Atomic Energy Commission is to discharge no activity to nature. Practically this is a very difficult thing to do. Tolerances will be set probably at or near the natural backgrounds for the areas involved.

The biggest lack at the moment is sufficient laboratory and semi-works development on the suggested processes. Much is planned but at the moment most sites are held up for facilities in which to do the work.

From preliminary investigations, it looks as though the goals can be met and further that no new and complicated equipment will have to be designed. It should be possible to solve all of these problems using conventional unit operations and commercially available equipment.

Disposal of Gaseous and Solid Wastes

According to A. E. Gorman operations which produce waste capable of causing atmospheric contamination include (1) material processing, (2) metallurgy and machining, (3) air-cooled nuclear reactor operation, (4) chemical separations, (5) laboratory research, and (6) incineration.

1. Preliminary preparation of metallic ores of interest in the atomic energy program requires such operations as drying, crushing, grinding, and sieving. Radioactive and toxic dusts are removed from the working space and the atmosphere by ordinary industrial types of mechanical separators, electrostatic precipitators and filters. Better decontaminating equipment is being installed in existing plants working on Commission contracts, and in new plants the Commission insists on installation of equipment capable of removing all contamination.

Similarly in the chemical processing of ores, the fumes, mists and gases are removed by ventilation, scrubbing and filtration before release to the atmosphere. The radiation hazard associated with uranium ores and the refined metal are not excessive in view of the low-level radioactivity of these products.

2. During the metallurgical and machining operations of such metals as beryllium and uranium contaminating fumes and dusts of the metallic oxides may develop. These are removed by ventilation and filtering in order not to contaminate the work areas or the outside atmosphere. The tentative permissible limit of atmospheric contamination by alpha emitting materials in working areas has been established at 5×10^{-7} micrograms or 3×10^{-8} microcuries per liter of air.

3. Air used for cooling a nuclear reactor or pile becomes radioactive, the most significant component being argon 41, having a half-life of 110 minutes. Carbon-14 is occasionally discharged in very small amounts which are believed to have no public health significance. Under abnormal conditions, uranium oxide and radioactive fission products may also contaminate the cooling air. These materials are removed by proper facilities including filters.

The only air-cooled pile now in actual operation is at Oak Ridge; this pile is equipped with electrostatic precipitators and filters which treat the cooling air before it leaves the stack. A second air-cooled reactor is now under construction at Brookhaven National Laboratory, Long Island. The air will be filtered before and after delivery to the pile and will be dispersed to the atmosphere at high velocity through a stack over 300 feet high. According to design considerations, atmospheric contamination in the neighborhood of the Brookhaven reactor will be no greater than 10^{-6} microcuries per liter. Operation of the pile will be subject to an elaborate system of meteorological forecasts and the level of operations will be governed accordingly.

High-powered reactors of the future probably will employ closed-cycle cooling systems which will not discharge gaseous wastes to the atmosphere. Should additional air-cooled reactors be constructed, their design will provide for pre- and post-filtering of the cooling air and operations will be regulated in accord with local meteorological conditions to prevent any degree of hazard.

4. The fission products of uranium exposed to neutron bombardment in a reactor are highly radioactive. These fission products are separated from unused uranium and plutonium by a variety of chemical processes. The equipment is largely automatic and operated by remote control. Provision is made to remove radioactive particles which might contaminate the atmosphere by scrubbing and filtering the dissolver off gases. Filters currently in

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use are made of special asbestos, glass fibers or sand.

Dissolving operations are not carried out when meteorological conditions are unfavorable, and elaborate facilities are maintained at the production areas in order to supply the necessary meteorological information. At operating areas ventilating exhaust air and dissolver off gases are discharged through high stacks 200 to 300 feet high.

Prior to the installation of exhaust air decontamination equipment, it was believed that a combination of high stacks and large volumes of diluting air would result in adequate diffusion of contamination. Air, ground and vegetation tests made in the vicinity of the stacks and at off-site locations many miles away indicated a possible need for decontaminating exhaust air prior to discharge to the stacks. This is now being done as described above.

Radioactive iodine, having a half-life of 8.3 days, was the principal contaminant. It was found in low amounts in vegetation many miles away. The permissible limit set for radioiodine contamination of vegetation is 0.2 microcuries per kilogram. For atmospheric contamination with radioiodine 3.5×10^{-5} microcuries per liter of air is the permissible limit. A small percentage of particles was found to have half-lives measured in months, while a very small amount consisted of long-lived particles having half-lives of a year or longer.

Careful consideration of this situation by the Commission's Advisory Committee on Biology and Medicine led to the conclusion that no undue public hazard had been created prior to the installation of decontaminating equipment. Since the installation of this equipment, the problem has been reduced although constant monitoring of air and vegetation in the vicinity of the stacks and for considerable distances around is carried on.

5. Gaseous effluents from research laboratories have varying levels of radioactivity. In new laboratories, high-level working areas are usually kept separate from low-level and so-called clean areas. The areas are served by separate ventilating facilities usually arranged so that even in emergency high-level activity can never contaminate an area of lower level. Inlet and exhaust air is filtered and monitored regularly. As a further precaution, in some laboratories having high-level activity, actual work is done in special sealed boxes set in ventilated hoods, manipulation of radioactive materials and equipment is carried on with protective gloves or by remote control.

At some of the older laboratories, especially where existing facilities were adapted for research on radioactive materials, facilities have not always been adequate to provide complete radioactive decontamination. These laboratories are being remodelled or replaced. The contrast between the original state of the older laboratories and the newer ones is striking and marks a step forward in the progress of the industry.

6. Burning of radioactive wastes and by-products cannot be followed unless provision is made to decontaminate the products of combustion. This requirement is not a simple one to meet, but studies for improving incineration methods are in progress.

Late in May, 1948, a group of industrial consultants was appointed to advise the Commission on stack gas problems. This committee of seven experts has recommended that special research be done on various immediate and fundamental problems in treating gaseous effluents peculiar to atomic energy operations. These projects include the development of more effective filters and filter materials, better methods of removal of iodine from dissolver

off gases, processes for bottling up of rare gases, development of an improved incinerator, studies of new types of mechanical and electrical decontaminating facilities, methods for more precise determination of particle sizes, standardization of sampling techniques, and the improvement of measuring instruments. In addition to efficiency, problems of cost are an important consideration in such research.

Radioactivity complicates the disposal of solid wastes in the atomic industry. Useful material and equipment are decontaminated and reclaimed where possible; otherwise they are buried in carefully selected burial grounds. The area is fenced and restricted. Earth cover of 10 to 12 feet usually assures adequate shielding; and the areas are monitored regularly. Certain radioactive waste materials from the Radiation Laboratory, Berkeley, California, are encased in large steel drums which are disposed of by dumping at sea many miles off shore. The research on incineration and other methods of disposing of solid wastes should considerably simplify the problem by reducing the volume of materials which must be buried.

Disposal of Wastes by Biochemical Treatment

The possibilities of using controlled microflora and fauna for the absorption and concentration of radioactive waste products, particularly those with long half-lives was discussed by C. C. Ruchhoft, who stated that at Oak Ridge and elsewhere it has been observed that the mechanical, chemical and biological processes of natural purification tend to reduce the intensity of the radioactivity of waters containing minute quantities of nuclear fission wastes. Examination of the bottom muds and biological flora and fauna of the discharge ponds and streams shows that these components absorb some of the radioactive constituents and thus serve as concentrators. It is also observed that algae and other aquatic plants may grow prolifically in water that has considerable radioactivity.

Experience with trickling filter and activated sludge processes for ordinary industrial and domestic wastes, indicates that a modification of the latter seems most promising for treatment of radioactive wastes. This process may be described as a biochemical reaction in which the organic materials are oxidized and assimilated by means of an activated sludge. The sludge is made up of massive colonies of bacteria embedded in a jellylike or gelatinous substance. When the bacterial cell membranes are swollen through the absorption of water they present an enormous surface area capable of holding radioactive materials.

Experiments with this process at Los Alamos indicate that more than 95% of a long half-life alpha emitter such as uranium or plutonium in concentrations up to 1.4 micrograms per liter may be successfully removed from the liquid and transferred to the sludge. This research suggests that a two-stage activated sludge process can be expected to remove 99% of plutonium from wastes, and produce an effluent that should approach a tolerance limit of 0.01 micrograms per liter.

Whether or not such processes will apply to other types of radioactive materials must be determined, and research studies are under way. Bacteria in activated sludge normally feed on the organic sewage material treated. In many areas where radioactive wastes are found adequate sewage is not available and methods for feeding the bacteria artificially must be developed. This will require a considerable amount of research in order to ascertain what supplementary nutrients including minerals are necessary to maintain active sludges of the proper characteristics.

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When such facts are known it will be possible to design and build a pilot plant to determine the over-all efficiency and cost of such biological concentration methods.

It is believed that biological concentration methods will be considerably less expensive than chemical methods for removing radioactive contaminants from liquids.

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EDITOR'S NOTE: From the list of titles translated by Dr. Ludmila Turkevich and Prof. John Turkevich for Vol. 1, No. 6, of the *Guide to Russian Scientific Periodical Literature* published by the Brookhaven National Laboratory, Upton, New York, the references below have been selected because of their interest to NUCLEONICS readers. Additional listings, as they are made available, will be published in future issues of NUCLEONICS.

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Surveying and Monitoring of Radiation from Radioisotopes*

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LABORATORY PERSONNEL can work safely with radioactive materials if all procedures are properly planned and executed in accordance with currently accepted techniques. Safe working conditions can be insured by accurate appraisal of radiation exposure and radiocontamination through the proper use of suitable instruments.

The importance of proper surveying and monitoring cannot be over-emphasized. Stated briefly, the purposes of surveying and monitoring are: (1) to evaluate procedures and techniques employed in minimizing external irradiation of personnel during an operation or laboratory procedure; (2) to measure the cumulative exposure to an individual over a period of time, such as a day or week, or the duration of a particular experiment; (3) to detect radioactive contaminants on surfaces and in the air. These purposes can be accomplished only if personnel are able to select suitable instruments, use them properly, and interpret the readings meaningfully.

MEASUREMENT OF RADIATION

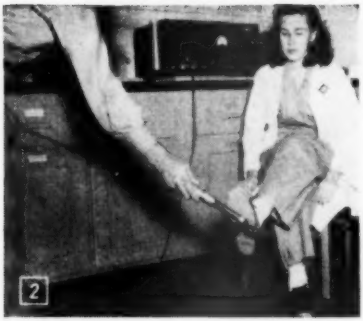
Detection of Radiation

The detection of energetic nuclear radiations is dependent upon the measurement of ionization induced in matter. This may be accomplished by applying an electrical field across the volume in which ionization occurs. The current produced by the ions is measured to estimate the rate at which energy of the radiation is dissipated in the volume considered. Ionizing radiations can also be detected by photochemical, fluorescent, and other methods.

There are two principal types of radiation survey and monitoring instruments: those giving counts and thus an indication of the ionization produced by individual particles; and those giving dosages or dosage rates and thus an indication of the dissipation of radiation energy in a medium. The former type includes counters, whereas the latter type includes film badges for measuring dosages and certain ionization chambers for measuring dosage rates. In general, counters, such as those employing Geiger-Müller tubes, have the higher sensitivity, making them more suitable for quick measurement of low activities. Instruments of the ionization-chamber type usually have a greater range of measurement and are less energy-dependent.

An ideal radiation survey instrument should accurately measure dosage rates over a range of < 0.1 mr/hr to $> 4{,}000$ mr/hr. At present such equipment is not available on the market, thereby necessitating selection of instruments for specific ranges. Table 1 is included as a rough guide for the selection of health physics survey instruments. Some of the instruments listed in this table are illustrated in Fig. 1.

* This paper is limited to the discussion of isotopes emitting beta and gamma radiation, since no other radioisotopes are distributed by the Atomic Energy Commission at present.



Monitoring of hands, feet and clothing: (1) checking hands, (2) checking feet, (3) four-fold counter to check both hands and feet simultaneously, (4) checking clothing

Maximum Permissible Exposure

The National Committee on Radiation Protection, sponsored by Bureau of Standards, under the chairmanship of L. S. Taylor, has been studying the question of maximum permissible radiation exposure. Up to the present time, 0.1 roentgen* per 24 hours has been accepted as the maximum permissible exposure value. More recently, however, several subcommittees of the NRC have unofficially agreed upon a revised permissible value of 0.3 r per week (or 0.3 roentgen-equivalent-physical† for beta radiation).‡

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* The roentgen unit (r) is that quantity of X- or gamma-radiation such that the associated corpuscular emission per 0.001293 gm of air produces, in air, ions carrying 1 electrostatic unit of quantity of electricity of either sign (*1*).

† If the energy lost by ionization in the tissues is the same as the energy loss for one roentgen of gamma radiation absorbed in air, the dose is spoken of as one roentgen-equivalent-physical (abbreviated "rep") (*1*).

‡ 0.3 rep indicates beta particle irradiation of the whole body. Higher dosage values will probably be set for limited areas of the body, such as the hands.

FIG. 1. Some survey instruments: (left to right) Zeus, Cutie Pie, Lauritsen electroscope, alpha-beta-gamma survey meter, Beckman ionization chamber

These values are being widely accepted and indicate the trend of thought at present.

TECHNIQUES IN SURVEYING

Unshielded Gamma Quanta Sources

By application of the inverse square law to gamma quanta emanating from an unshielded point source, the dosage rate can be estimated at one point from measurements taken at another point. This procedure is only applicable for

TABLE 1

Some Health Physics Survey Meters*

Instrument	*Weight (lbs.)*	*Size (in.)*	*Radiation Detected*	*Usual Accurate Sensitivity Range in mr/hr†*	*Most Useful Purpose*
Lauritsen electroscope	8	8 × 3 × 14	Beta Gamma	<0.1–1000	Measuring dosage rates. Instrument response too slow for measuring low-activity contamination
Portable Geiger-Müller instruments	2–15	7 × 5 × 4 (average)	Beta Gamma	<0.1–15 to 20	Detecting surface contamination. (Low-energy beta particles can be detected with suitable thin-walled tubes
Cutie pie meter	4	12 × 3 × 8	Beta Gamma	10–5000	Measuring dosage rates
Zeus	10	12½ × 6½ × 5	Beta Gamma	5–5000	Measuring dosage rates
Commercial model of Zeuto	6	9½ × 5 × 6	Beta (Alpha)	<0.1–40	Measuring dosage rates. Detecting surface contamination
Juno meter	5	9 × 5¼ × 4	Beta, Gamma (Alpha)	5–4000	Measuring dosage rates
Scaler (G. M. tube on cable)	40–100	21 × 15 × 10½	Beta Gamma	<0.1–15 to 20	Detecting surface contamination. (Low-energy beta particles can be detected with suitable thin-walled tubes.)

* The inclusion or exclusion of specific instruments in this table does not necessarily endorse or disapprove their use.

† Davis, D. M., "Health Physics Instrument Manual," Health Physics Dept., O.R.N.L.

estimating dosage rates at locations beyond which the radiation acts as a point source.* The reading, however, must be taken with the instrument chamber at a distance from the location where the radioactive source begins to act as a true point source equivalent to at least twice the reference dimension of the chamber. Distances are usually measured from the center of the source to the center of the chamber. The effective center and the actual center of the chamber may not coincide. This lack of coincidence may be more noticeable when the instrument is close to a source of high intensity.

The dosage rate at the surface of a diffuse source cannot be determined by placing the instrument chamber adjacent to it.

To assist the isotope user in estimating dosage rates from point-source emitters of gamma quanta, certain theoretical values are included in Table 2.

Unshielded Beta Sources

Each beta emitter decays with the emission of particles having a spectrum of energies varying from nearly 0 to some maximum energy, E_{max}. Consequently, the increase in radiation intensity as one approaches a beta source is greater than would be predicted by the inverse square law. Due to the low penetrability of beta particles, one must consider the thickness of the open-window portion of the survey instrument or the wall of the G-M tube used. This consideration permits an estimation of the percentage of beta particles measured. Instrument readings due to beta radiation can be interpreted in terms of "reps" only if calibrated with a suitable beta particle source.

* For practical purposes a source may be regarded as a point when the distance from the source to the receptor is equal to or greater than the dimensions of the source.

TABLE 2

Calculated Dosage Rate at One Foot from Point-source Gamma Emitters (2)

E*(Mev)	*r/hr per curie or mr/hr per mc at one foot*
0.1	0.5
0.2	1.1
0.3	1.8
0.5	3.1
0.8	5.0
1.0	6.0
1.5	8.2
2.0	10
2.5	11.6
3	13
4	15

* One photon per disintegration is assumed. If the number of photons per disintegration is other than one, the value should be adjusted accordingly. See "1947 Summary of Nuclear Data," NUCLEONICS 2, No. 5, Part 2, (1948), and other references for data on decay schemes.

The relative absorption qualities of various materials used in radiation protection may be determined by placing sample sheets on frames designed to permit interchangeable mounting and placing the framed material between a source and a survey instrument. (For convenient reference, the range of beta particles in air as a function of energy is listed in Table 3.)

Unshielded Beta-gamma Sources

To estimate the dosage rate due to the respective radiation components of a beta-gamma emitter, separate readings under identical conditions in geometry may be taken with an instrument chamber having a window attachment. The open-window reading will indicate ionization due to both beta and gamma radiation, whereas the closed-window reading will indicate gamma radiation alone. Subtraction of the second from the first gives the reading due to beta radiation, except

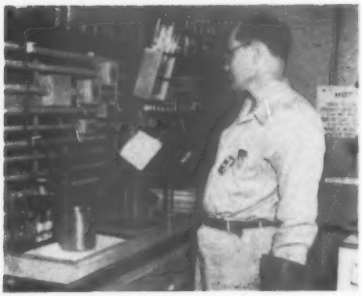


FIG. 2. Checking radiation cone and dosage rate

for extremely low-energy gamma radiation, which may be appreciably absorbed in the window material. (It is assumed that the window is sufficiently thick to absorb all beta radiation.)

Shielded Sources

In making surveys of shielded sources, the same general techniques may be applied to both point and diffuse sources. When sources are shielded on one or more sides, secondary and scattered radiation may be expected to contribute to the dosage rate.

An intensified field of radiation should be expected in the unshielded direction from a beta emitter confined in an open beaker, particularly if little radiation escapes through the sides of the beaker. The extent of the radiation cone and dosage rate can be determined by carefully orienting the instrument chamber while keeping the open window pointed in the direction for maximum radiation penetration (see Fig. 2). When beta particles are absorbed, secondary radiation, or Bremsstrahlung, is produced. This phenomenon should be considered and dosage rates determined with an appropriate survey instrument.

When gamma quanta emitters are confined, the dosage rate in the unshielded direction is also intensified. As with beta particles, the dosage rate of the intensified field can be accurately determined only by measurement.

When the investigator is working over or around a barrier-type shield, the area he occupies must be carefully surveyed, giving particular attention to the position of the head, hands, and chest, which may extend above the shield. In such cases dosage rates to other parts of the body should also be measured, since shielding under the source may not be adequate. When very intense gamma quanta sources are being used, scattering and secondary radiations may contribute to the overall radiation in the area. Because of the softness of these radiations, difficulty is often experienced in measuring them.

TABLE 3

Range of Beta Particles in Air (3)

Energy (Mev)	*Maximum Range of Beta Rays (Meters of air)*
.01	.0022
.02	.0072
.03	.015
.04	.024
.05	.037
.06	.050
.07	.064
.08	.080
.09	.095
.10	.11
.15	.21
.2	.36
.3	.65
.4	1.0
.6	1.8
.8	2.8
1.0	3.7
1.5	6.1
2.0	8.4
3.0	13
4.0	16
5.0	19

Collimated Beams of Gamma Quanta

Dosage rate values in collimated gamma beams can best be determined

by direct measurement. Instruments are calibrated with the entire volume of the chamber subjected to uniform radiation intensity. A true reading of the intensity of a beam can be obtained only when this condition is realized. The fact that the sensitivity of some instrument chambers varies from one part to another contributes further to the inaccuracy in measuring a highly collimated beam. Collimated beams of small cross-section areas escaping from shields are difficult to detect with ordinary ionization chambers, but can be readily detected with Geiger-Müller instruments. Thimble-type ionization chambers and personnel monitoring films are well suited for measuring these beams.

SURVEY OF LAB OPERATIONS

Survey of Procedures

Safe working conditions, as stated previously, are assured only through proper appraisal of dosage rates by adequate measurements. These measurements supply information from which the adaptation of technique, adjustment of working distance, shielding, and exposure working time can be correlated to minimize exposure.

In addition to surveying operations, it is also necessary to survey areas in which active materials are stored and facilities through which they are disposed.

In general, before one works in a field of radiation, direct measurements should be made to determine the dosage rate. Relying solely upon calculated dosage rates is likely to lead to unnecessary exposure. Arbitrarily, the limit above which a radiation survey is required during the course of an experiment is 50 to 300 microcuries. Recommended values for individual isotopes are dependent upon the conditions involved. Surveys should, however, be made as conditions dictate, and reliance should not be placed upon arbitrary values.

In most simple operations, a survey at the beginning and at the end of the procedure will suffice. When a new and different operation is initiated, surveys should be made of each step. Some operations, however, may require survey of each step regardless of the number of times repeated, such as: (1) opening the shipping containers and removing the contents, (2) dissolving the radioisotope, (3) sampling for assay, (4) diluting to desired concentration, (5) adjusting *p*H and/or salt concentration, (6) chemically purifying or sterilizing, and (7) administering the radioisotope.

Table 4 will serve as a guide for establishing preliminary dosage rates in planning experiments involving gamma quanta emitters.

Operations are surveyed by orienting the instrument chamber for maximum geometry as it is moved slowly with relation to a worker's position. During this procedure, caution must be exercised to avoid the tendency to survey the source rather than the location of the individual. When an operation is surveyed, the geometric relationship of the source to the location of the individual should be visualized.

The hand-to-chest exposure ratio is much higher for beta radiation than for gamma radiation. Experiments (4) have shown that if no special precautions are taken while working with a beta emitter having an E_{max} of 0.5 Mev or higher, the hand-to-chest ratio may vary from 100:1 to 1000:1. If proper techniques are followed, however, this exposure ratio may be reduced to 3:1.

It is extremely important that one survey each step of an operation in which evaporation takes place. During these procedures, especially the ones which involve a beta emitter, the cone of intensified radiation becomes

TABLE 4

Calculated Permissible Exposure Range in Centimeters for Point-source Gamma Radiation Emitters

(Permissible Exposure—6.25 mr/hr)

E^*(Mev)	Millicuries										
	.25	.50	1	5	10	20	30	40	50	75	100
.1	4.27	6.10	8.53	19.20	27.13	38.10	47.24	54.56	60.96	74.68	86.26
.2	6.40	9.14	12.80	28.65	40.54	57.30	70.10	81.08	90.83	110.64	128.32
.3	8.23	11.58	16.46	36.81	51.82	73.15	89.61	103.63	115.82	141.73	163.68
.5	10.67	15.24	21.34	47.71	67.97	96.01	117.65	135.94	151.79	185.93	214.58
.8	13.72	19.20	27.13	60.96	86.26	121.92	149.05	172.21	192.63	236.22	272.49
1.0	14.94	21.03	29.87	66.75	94.49	133.81	163.68	188.98	211.23	259.08	298.70
1.5	17.37	24.69	35.05	78.03	110.34	156.06	191.11	220.68	246.04	301.37	348.01
2.0	19.20	27.43	38.10	86.26	121.92	172.21	211.23	243.84	272.49	333.76	385.57
2.5	20.73	29.26	41.76	92.96	131.37	185.93	227.32	262.74	293.54	359.36	415.14
3.0	21.95	31.09	43.89	98.25	138.99	196.90	240.79	277.92	310.66	380.70	439.52
4.0	23.62	33.53	47.24	105.46	149.05	211.23	258.47	298.40	333.76	408.74	472.44

* One photon of this energy per disintegration is assumed.

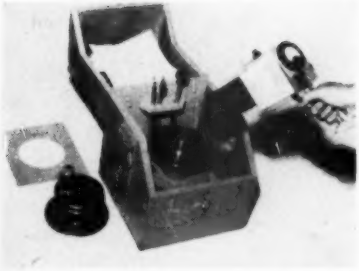
more pronounced as dryness is approached. This, of course, is due to the reduction in self-absorption from diminution in liquid content. One may appraise the dosage rates with a survey instrument. Film meters are particularly well adapted for determining exposure to the hands (see Fig. 3).

When an isotope is shipped from Oak Ridge, the dosage rate at the surface of the shipping container is not greater than 15 mr/hr. Upon receipt of the shipment, the container should not be opened until all necessary equipment is available for safe performance of the operations involved. Examples of steps to be surveyed while removing an irradiated unit are illustrated in Fig. 4.

FIG. 3. Film meters for checking hand exposure

Extreme caution and careful manipulations are necessary in handling any amount of radioactive material. In work involving millicurie quantities of activity, it is advisable to carry out practice trials or dry runs to avoid unforeseen difficulties. A step of a survey procedure used during a typical laboratory operation involving microcurie quantities of gamma-quanta-emitting material is shown in Fig. 5. A similar procedure involving millicurie quantities of the same material is shown in Fig. 6.

Some survey instruments are not stable and require experience in operation and caution in the interpretation of readings. If instruments are used infrequently, they should be checked with a source of known activity before each use. After an instrument is turned on, sufficient time must be



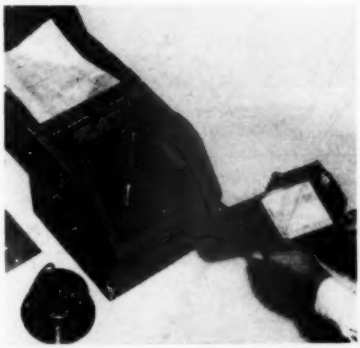


FIG. 4. Four surveying steps necessary in removal of an irradiated unit from the shipping container

allowed for it to warm up; and when in use, it must be allowed sufficient time to respond to the field of radiation. If the instrument comes in physical contact with other objects during a survey, false readings may result. Also, instrument contamination must be avoided. If instruments are used in areas where contamination is likely, the chamber should be covered with an easily removable material such as masking tape.

Air Monitoring

When an operation is being performed with radioactive materials, the possibility of air contamination during routine procedures and in cases of accident must be considered. In the event of possible air contamination, means for respiratory protection and air monitoring should be provided. The former can be afforded by U. S. Army assault masks, demand-type respirators, or air-line hoods. In the latter, air may be sampled for radioactivity in the form of dust or spray by drawing it through an electrostatic precipitator (Fig. 7). The electrostatic precipitator deposits the material on an aluminum foil, which is later removed and counted by a suitable counter. When a precipitator is used, it is important to maintain proper voltage regulation, as collection efficiency is voltage-dependent.

Microcuries of beta and gamma radiation emitters per air sample can be determined by substitution in the following formulas (*5*) if an electrostatic

FIG. 5. Surveying an operation involving microcurie quantities of gamma-quanta emitting material

FIG. 6. Similar procedure as in (5) using millicurie quantities

precipitator is used:

$$\mu c/\text{sample} = \frac{\text{counts/minute}}{\text{counter efficiency} \times \text{counter geometry}} \times \frac{1}{\frac{(3.7 \times 10^{10})}{(\text{d/sec/curie})} \times \frac{60}{(\text{sec to min})} \times \frac{10^{-6}}{(\text{convert to } \mu c)}} \quad (1)$$

Microcuries per sample* are converted to μc/cc of air as follows:

$$\mu c/\text{cc of air} = \frac{\mu c/\text{sample}}{(\text{collection efficiency}) \times (\text{cc of air drawn through the precipitron})} \quad (2)$$

Another method of sampling consists of drawing a known volume of air through filter paper which is subsequently removed and counted. In this case, care must be exercised to prevent leakage around the edges of the filter. The filter sampler may be adapted for constant air monitoring by placing the filter around a shielded G-M tube and drawing air through it as the cumulative reading is recorded. Standard laboratory counting instruments may be used to count the samples in all cases.

If the radioactive material in the air is a gas or vapor, it may be sampled by drawing the air through an ion chamber and measuring the ion current with a suitable electrometer circuit. This method is not applicable for measuring low-level activities, but may be used as a continuous monitoring device to record high levels of contamination. Another method consists of collecting samples in evacuated chambers and counting them with suitable counters. The latter method presents difficulties, such as the contamination of the counter and the equilibration of the sample with the residual gas in the evacuated shield containing the counter tube.

In the determination of the degree of air contamination due to the presence of long-lived radioactive materials, it is necessary to make corrections for the beta and gamma radioactivity due to naturally occurring radon and thoron decay products. The natural background will vary with locality and atmospheric conditions, such as rainfall, temperature, wind strength and direction, etc. The radioactivity of these decay products is reduced to $< 4\%$ of their original value within

* Samples are usually collected over a 30-minute period.

three hours. A second count after 20 hours permits corrections for the presence of naturally occurring contaminants by substitution in the following formula (5):

$$C_{LL} = \frac{C_2 - C_1 T}{1 - T} \qquad (3)$$

where C_{LL} = count due to long-lived activity (i.e., activity of longer half-life than radon and thoron decay products normally found in the air)

C_1 = first count

C_2 = second count (at least 16 hours after C_1)

$T = e^{-\lambda \Delta t}$ when $\lambda = 0.0655$ (from half-life of thorium B)

$\Delta t = t_2 - t_1$ in hours

Survey of Surfaces

Surveys of surfaces where either beta or gamma emitters are used should preferably be made with an instrument having a sensitivity greater than 0.1 mr/hr. Instruments employing G-M tubes are especially suitable for detecting the presence of these radiocontaminants. These instruments also have the advantage of rapid response. They are, however, energy-dependent, and unless properly calibrated, should not be used for quantitative measurements.

Surveys for the presence of low-energy beta emitters, such as carbon-14 and sulfur-35, can be made with instruments such as a suitable thin-window G-M counter or an especially adapted "Poppy" (Fig. 8).

A surface is surveyed by moving the sensitive portion of the instrument in close proximity to it (Fig. 9). When radioactivity is detected, the source can be located by directive shielding. Even after efforts have been made to decontaminate an area, tests should be made to determine whether the active material will rub off the decontaminated

FIG. 7. An electrostatic precipitator

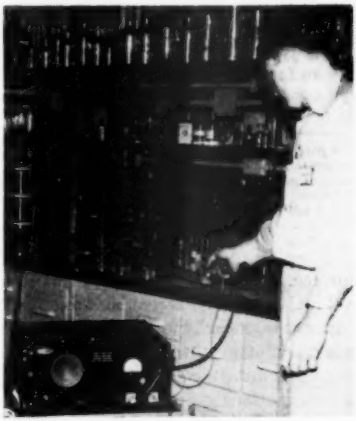


FIG. 8. Use of a "Poppy" for low-energy beta surveys

FIG. 9. Surveying a surface

TABLE 5

Suggested Limits for Radioactive Contamination

Item	*Maximum Permissible Contamination (Beta and Gamma)*
(1) Air	10^{-11} mc/cc (*6*)
(2) Water	10^{-7} mc/cc (*6*)
(3) Clothing	0.1 mr/hr or equivalent*
(4) Work area surfaces	0.1 mr/hr or equivalent*
(5) Body surfaces	0.05 mr/hr or equivalent*
(6) Smear tests on table tops, floor, equipment, etc. (2-square-inch filter paper smeared over an area of 12 sq. in.)	0.05 mr/hr or equivalent*

* Such derived tolerances are arbitrary and dependent upon the circumstances. 300 cpm with standard Eck and Krebs thin-walled glass counter with an effective flat plate area of ~ 5.4 cm² is roughly equivalent to 0.1 mr/hr.

surface. This is accomplished by using a 2-inch-square surface of suitable filter paper to smear the test area. The paper is then counted. This method is not recommended for quantitative determinations. Suggested maximum permissible limits of radiocontamination are shown in Table 5.

Equipment should also be surveyed for radiocontamination after use and before transfer to other areas.

Surveys for radiocontamination should include exposed structural surfaces, such as bench-tops, hoods, floors, drainboards, sinks, drains and other plumbing fixtures, handles, chairs, radioactive waste containers, glassware, and other apparatus. Shipping containers should also be included in such surveys.

Surveys are as important in clinical work as in laboratory and field work. Specifically, surveys should include such items as the patient's clothing, bed, linens, bed-tables, urinals, toilets, bed-pans, sputum cups, and articles used in the preparation and administration of the active materials.

All laboratories should formulate rules governing surveys for radioactive contamination. The required frequency for such surveys will depend upon the type and quantity of radioactive materials, the nature of the procedures, and the precautionary steps taken. Generally, routine surveys should be made at least once each week.

Personnel Monitoring

Routine personnel monitoring is accomplished by each individual's wearing a suitable radiation detection meter or meters. Preferably, these meters should be worn on the part of the body most likely to receive maximum dosage. In practice, however, they are often worn on the chest or waist. Under these conditions, care must be exercised in interpreting body exposure in terms of meter readings, particularly when one is working with beta radiation or narrow-beam gamma radiation.

The three types of meters considered most suitable for personnel monitoring are (1) ionization pocket meter of the condenser type, (2) ionization chamber with a quartz fiber indicator (dosimeter), and (3) film packets (see Fig. 10). One or more of these meters should be worn by all personnel handling more than 100 microcuries of any radioisotope which emits radiations capable of being measured with these instruments. Some investigators feel that it is desirable to wear personnel monitoring meters regardless of the level of activity involved.

When personnel are working with gamma-photon-emitters, any of the above-mentioned meters are satisfactory. The condenser-type meters usually have a reliable range of 10 mr to approximately 280 mr. It is important

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that care be exercised in reading these meters. Because of the possibility of erroneous discharge, it has been the policy of AEC laboratories to require each individual to wear two meters in juxtaposition, and to accept the lower reading as significant. It is imperative that a pocket meter be calibrated and read on the same instrument.

The dosimeter is equipped with a self-contained scale, enabling one to read the degree of discharge and thereby eliminating the need of an instrument for this purpose. This characteristic adapts it for monitoring "hot" operations where time limits cannot be accurately set from radiation survey. Most commercial instruments of this type have a sensitivity range of 10 mr to 200 mr. Condenser-type pocket chambers and dosimeters should be stored in a desiccator when not in use.

Films are usually worn during a special procedure or for a period of one week. They provide a permanent cumulative record of the radiation exposure of the wearer. A film packet, except for a small portion which is referred to as an open window, is usually encased in a shield, such as 1 mm of cadmium. The shield is used to filter out part of the low-energy gamma photon radiation, in order to render the meter less energy-dependent, and to give a discriminating reading when exposed to both beta and gamma radiation. The film packet consists of a sensitive and an insensitive film, which give a useful dosage value for gamma radiation in a range of 30 mr to 20,000 mr.

Films can be used to monitor personnel working with pure beta emitters, provided the beta radiation energy spectrum is sufficiently high to enable most of the particles to penetrate the covering of the film packet. Neither ordinary pocket meters nor dosimeters, however, should be used for this purpose. Films can also be used for

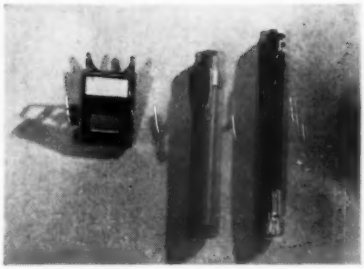

FIG. 10. Personnel monitoring meters: (left to right) film meter, dosimeter, condenser-type pocket meter

monitoring purposes when one is working with emitters of beta-gamma radiation.

Experiments (7) indicate that both the sensitive and insensitive films used in personnel monitoring are energy-independent to roentgen rays above 0.4 Mev. Films shielded with 1 mm of cadmium show much less energy-dependence to gamma rays of less than 0.4 Mev than is shown by unshielded films. Tests (7) on Victoreen pocket meters indicate that they are energy-independent for gamma photons greater than 0.25 Mev.

Monitoring of Hands, Feet, and Clothing

Hands and shoes should be monitored immediately after each procedure in which contamination is likely, and routinely before leaving the work area (see page 24). Also before eating or smoking one should wash and check the hands.

In the larger institutions, it may be desirable to install special counters to check the hands and feet simultaneously. These four-fold hand counters operate automatically for a predetermined period (see illustration on p. 24). Such units should be located near the washroom and dressing room.

Protective clothing worn in the laboratory should also be frequently scanned for contamination (see p. 24).

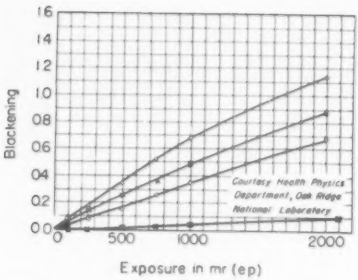

FIG. 11. Calibration curves for various combinations of film sensitivities, shielding, and types of radiation

If necessary, it should be decontaminated before being sent to the laundry.

Instrument Calibration

Health physics instruments used for measuring gamma radiation may be calibrated with any suitable source, radium and cobalt-60 being the most widely used. Radium standards are in equilibrium with their short-lived decay products. They are usually enclosed in platinum of ½ or 1 mm thickness. Calibration sources may be shielded in lead containers and moved into reference position by suitable remote-control devices. To determine the dosage rate of a radium standard source, the following equation (*8*) may be used:

$$r/hr = 8.98m(1 - 0.12t),$$

where r/hr is dosage rate measured in roentgens per hour at 1 cm, m is the mass of radium measured in milligrams, and t is the thickness of the platinum filter measured in mm. This equation is applicable only if the radium used is in equilibrium with its decay products and if the thickness of the filter is equal to or greater than 0.3 mm. In the calibration of an instrument, the source should be positioned to minimize scattering and secondary radiation.

An instrument is calibrated by placing the center of the chamber at varying distances of known dosage rate from the radioactive source and noting the response. Unless linearity of each scale has been determined experimentally, it is necessary to run a calibration curve on each scale. Moreover, calibration curves should not be extrapolated beyond the range of experimental data. Readings should not be taken at distances too close to the source so as to be invalidated by geometrical considerations.

Films may be calibrated by correlating developed film densities produced by exposure with known dosage values (Fig. 11). Separate calibration curves should be established for measuring the dosage produced by each type of radiation. Because of the many variable factors introduced in developing films, it is necessary to develop calibration films under the same controlled conditions used in processing monitoring films.

Even though instruments may retain their calibration over a period of a few months under ideal conditions, the optimum interval for survey meters should not be greater than one month.

Uranium (UX_2) may be used for calibrating beta radiation detection instruments. Calculations by Parker (*9*) indicate that the reading at the surface of this metal is 280 milliroentgens-equivalent-physical per hour.

Survey, Monitoring, and Calibration Records

Personnel monitoring data should be retained as a permanent record. Survey records of operations and of contamination should also be maintained. Forms to facilitate quick reference and easy maintenance should be established for this information. If films are retained as a permanent record, the calibrated films must also be filed.

* * *

Some of the photographs used in this paper were made available through the cooperation of the Health Physics Department, Oak Ridge National Laboratory.

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W. G. Gulley, Four-Fold Hand Counter, MDDC 899

SECRECY is the enemy of both science and democracy. Secrecy destroys that freedom of intellectual life upon which the advance of knowledge depends; it prevents the open and responsible management of the affairs of a democratic state. Our national security requires secrecy with respect to many things—our weapons of war, our military and naval strategy, and all matters which, if known, would increase our vulnerability to attack. The government has decided that what we have learned and are in the process of learning about the atomic bomb and its scientific context must be rigidly safeguarded. And it follows, of course, that wide discretion must be given to the responsible officers whose job it is to see that these secrets are kept. The great and persistent danger is that the secrecy necessary to military success in time of war will be needlessly continued in time of peace, and that under the pretext of protecting the national safety we shall withdraw from the area of common knowledge and free public discussion matters having nothing to do with national safety.

—Robert E. Cushman, in a speech before the American Physical Society on January 27, 1949

"Big Permanent Magnet" for focusing alpha particles. View of vertical gap

Recent Progress in Alpha-ray Spectroscopy

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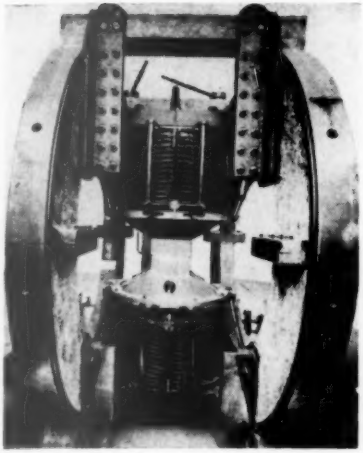
SINCE 1937 it seemed that marked progress in α-ray spectroscopy would be possible only if more convenient and elaborate means of detection and separation of different α-ray groups were to become available. The great advances made in β-ray spectroscopy by the use of permanent magnets suggested the possibility of using a sufficiently powerful permanent magnet to focus α-particles. The Centre National de la Recherche Scientifique in France gave a grant for the necessary funds and, in 1937, in collaboration with Monsieur Tasi, the project known as the "Big Permanent Magnet" was begun.

Because of the war, work was unfortunately delayed and it is only since 1947 that the "Laboratoire du Grand Aimant Permanent of Bellevue" has come into existence.

The Permanent Magnet

A short account is given here of the construction of this magnet. Fuller details can be found elsewhere (*1*, *2*, *3*).

The magnet, weighing 70 tons, is set in a concrete pit 1 m deep, so that the gap is at a convenient height. The framework consists of two large mild steel rings of 4.20 m external diameter and of 0.25 m thickness, the inner diameter being 2.70 m. The two rings which face each other are connected at two places by blocks of mild steel. These blocks carry the magnetic cores and the excitation coils. Two pole



View of horizontal gap

pieces of a special shape are attached to the cores. The gap between the pole pieces is thus easily accessible from all four sides. One of the blocks is permanently fixed to the two rings, while the other is adjustable between them in order to vary the gap between the pole pieces which can take any value between 0 and 30 cm. The circular form of the whole magnet makes it possible to orientate it in space, the magnet being placed on four rollers. (See photographs above.)

The pole cores consist of two cylinders of 1.20 m diameter and 0.75 m height. The walls of the cylinders are made of 1 cm nonmagnetic steel. The bottom and the top of the cylinder consist of 10 cm thick mild steel. Each cylinder contains 5,750 kg of a nickel-aluminium alloy. The individual magnets have the dimension $21 \times 62 \times 380$ mm. They are piled up inside each cylinder in two rows. Each pole piece consists of a mild steel block of a special form which carries a prism-shaped part of $44 \times 78 \times 22$ cm.

For a gap of 2 cm, one obtains a field of roughly 12,500 gauss. Under the same conditions but for a pole-distance of 1 cm, the field is about 17,000 gauss. As a rule, the gap of 2 cm is used because it is sufficient for the study of α-ray particles having an $H\rho$ of 400,000 gauss-cm. It is interesting to note that the $H\rho$ of the common β-rays are of the order of 5,000.

It is well known (*4*, *5*) that marked progress has been made toward detection of individual high-velocity particles as a result of advances in the technique of manufacture and development of photographic emulsions. These new emulsions, therefore, were used in the study of α-ray spectroscopy with the permanent magnet (Figs. 1, 2, and 3).

Fine Structure and Atomic Number

Many physicists have long remarked, and probably independently, that by plotting the energies of the α-particles as a function of the mass numbers of the emitting elements, one obtains almost straight lines for the same Z values. It is more than probable that these curves will one day have a similar importance for α-ray spectroscopy, as the curves of Moseley have had for X-ray spectroscopy.

Having at his disposal data concerning the fine-structure of α-rays, the author mentioned in 1934 (*6*) that the complexity of the fine-structure seemed to go up with the ratio Z/A of the emitting element. This ratio increases generally with the half-life of the elements, and in fact it was found that the complexity of the magnetic spectra of α-particles increased for elements with long lifetime. It was thus important to analyze magnetic spectra of α-rays of elements having a long lifetime. Unfortunately, the experimental difficulties increase when one studies elements with long lifetime.

It is well known that the phenomena of "slowing down" and "struggling" of

FIG. 1. Alpha-ray tracks occurring in the peak of α_1 of ThC

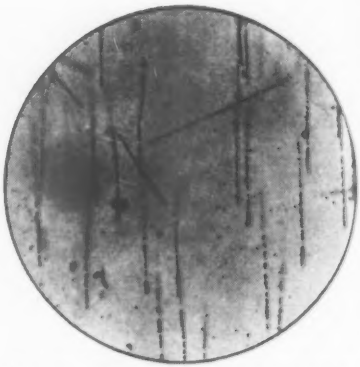


FIG. 2. Alpha-ray tracks occurring in the low-velocity side of α_1 of ThC. Stray particles visible were probably reflected by the walls

α-particles become important when one works with a thickness of matter which cannot be neglected. When sufficiently thin layers are used, it is necessary to increase considerably the times of exposures; then the advantages of a permanent magnet become obvious.

The high stability of the magnetic field of the permanent magnet over a period of time, combined with the individual registration of each particle by means of the photographic plates, enables us to integrate weak radiations and thus to make a more detailed study of the α-ray emission of elements of

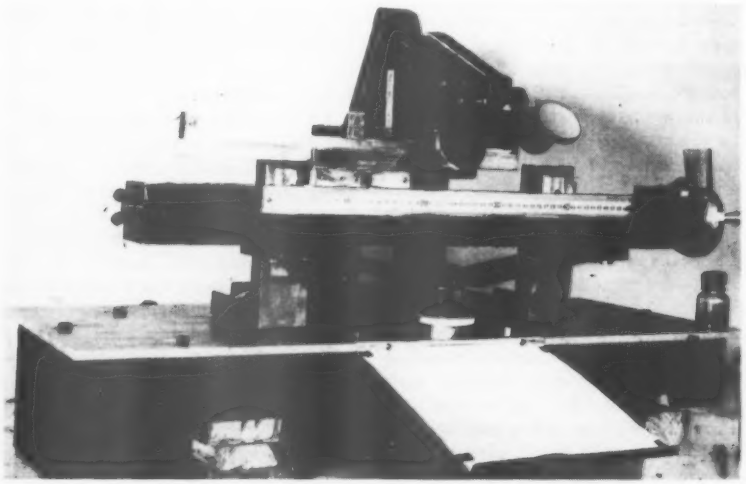


FIG. 3. Projection microscope for the study of 18 by 18 mm photographic plates. Plates can be moved by precision screws along two perpendicular axes

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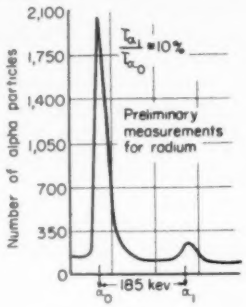
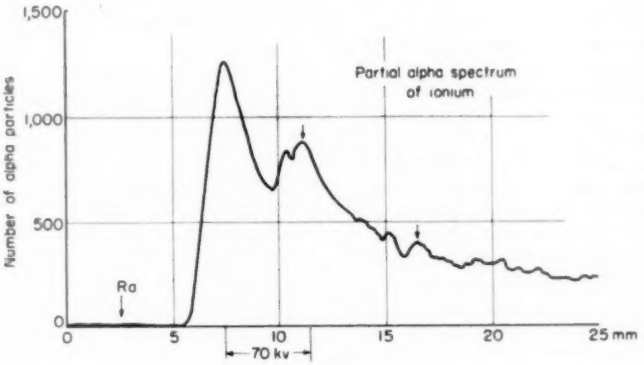
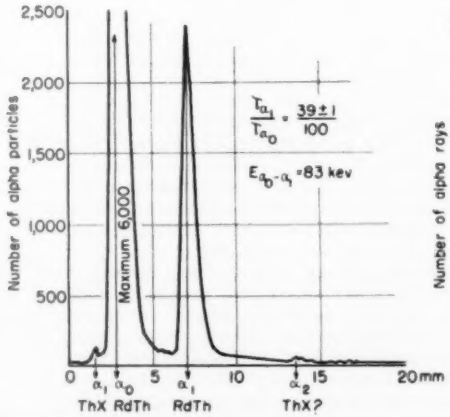
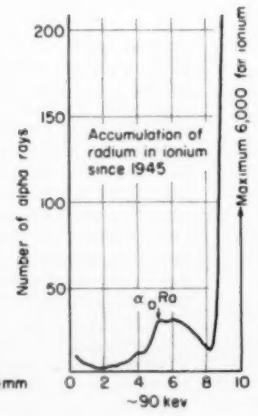


FIG. 4. Examples of curves for some elements recently under study at the Laboratoire du Grand Aimant Permanent







long lifetime. The total emitted spectrum is simultaneously recorded. On the other hand, in the case of short-lived elements, the high homogeneity of the field permits examination of small energy differences in greater detail. In favorable circumstances one can detect energy differences of 3 kev for a total energy of 6,000 kev. A certain amount of progress has also been made in the precision of the intensity ratio of complex spectra (RdTh).

In order to show the potentialities of the method, a few examples of curves of elements recently studied in the laboratory are shown in Fig. 4.

In the case of ionium which has a mean lifetime of the order of 10^5 years, we (together with Valadares and Vial) were able to measure, for the first time by magnetic deviation, the energy of the emitted particles, and simultaneously resolve the complex emitted spectrum.

For ionium, we used exposures up to 21 days. The two main groups separated by roughly 70 kev can be distinguished on the plates with the naked eye after an exposure of 4 days. In the case of thorium X, we (together with Perey, Valadares and Vial) found two new low-energy groups. In the case of radiothorium, we (together with Valadares and Perey) were able to determine with greater exactitude the energy differences and the intensities of the main groups. The spectra of the family of protactinium and radium are still being studied.

We believe that in the not-too-far future a more exact and detailed study of the α-spectra of all available elements might allow us to determine the relation between the energies of emission and the mass, charge, and, possibly, spin of the emitting elements.

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SOME of the raw material exploration activities carried on by the U. S. Geological Survey and the AEC include the following: (1) Geologic study and exploration of the vanadium-uranium ores of the Colorado plateau; (2) Geologic study of the uranium-bearing phosphate and shale formations of the country; (3) A systematic examination of all mine dumps, mill tailings, smelter slag, and similar products for radioactive minerals; (4) A systematic study and frequent logging of oil and gas well holes for evidences of radioactive material; (5) Reconnaissance studies of so-called geologically favorable areas for evidences of unusually radioactive materials; (6) Spot examinations of all reported uranium prospects believed to have some chance of being important; (7) Geologic reconnaissance of river placer and beach sand deposits to locate large potential sources of monazite for use if thorium becomes a fuel for nuclear reactors; (8) Examination of pegmatites as possible sources of uranium and beryllium; (9) Special studies in connection with existing or proposed nuclear reactor sites, such as Hanford, where there are big and complex problems associated with water supply and waste disposal; and (10) Laboratory studies of many kinds involving the mineralogy and chemistry of uranium.

URANIUM HYDRIDE—III

DISPERSIONS IN MERCURY*

Last of a series of three papers discussing the studies carried out at the Ames laboratory following preparation of uranium hydride from the massive metal for the first time early in 1943

BY

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IN SOME EXPERIMENTS with a uranium-gold alloy, a sample was treated with hydrogen at 250° until a powder resulted, and an attempt was made to separate any elementary gold by amalgamation. It was observed that the entire mass was wetted by the mercury, and appeared to dissolve. Samples of pure uranium hydride behaved similarly. Subsequent evidence indicated that these extraordinary "amalgams" were not true solutions, but suspensions. In this paper they are referred to, for brevity, as *uranium-hydride amalgams*, although this name is not strictly accurate.

Formation and physical properties (*1*, *2*). A series of uranium-hydride samples prepared from pure uranium was treated with mercury, forming amalgams of increasing hydride concentration. The preparations were extremely bright and shiny, and some had a marked tendency to adhere to the glass walls of the vessel. Close examination of the amalgams revealed the presence of a few unaffected particles; these were probably the impurities present in the original metal. It was observed that hydride samples which had been briefly exposed to air prior to the mercury treatment were not wetted and did not amalgamate. Uranium deuteride formed amalgams indistinguishable in appearance from the hydride amalgams. When uranium-hydride amalgams were prepared, no heat was evolved. This was in contrast to the process of forming amalgams of uranium metal (prepared from mercury and powdered uranium from the decomposition of the hydride), when a small but definite amount of heat was liberated as uranium-mercury intermetallic compounds were formed.

The consistency and appearance of uranium hydride amalgams as a function of concentration are indicated in Table 1.

Samples of semiliquid amalgams were filtered centrifugally through porous alundum disks in an inert atmosphere. It was found that the filtrate contained less than 0.1% uranium, while the residue was a more concentrated,

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* This paper is based on work done for the Plutonium Project of the Manhattan District in 1943–44 and was first reported in Plutonium Project Reports CC-925, CC-1059, CC-1091, and CC-1524.

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TABLE 1

Variation of the Properties of Uranium Hydride Amalgams with Concentration

Concentration weight % UH_3	*Description*
10	Much like mercury itself; scarcely adhered to glass
20	Definitely more viscous; adhered to glass; had appearance of gallium metal
30	Semi-fluid mass; adhered to glass readily
40	Semi-solid; hardly flowed; adhered to glass
50	Stiff semi-solid; did not flow; adhered to glass
60	Borderline between solid and semi-solid; adhered to glass in spots
70	Light gray metallic-looking powder; did not adhere to glass
80	Gray powder; pyrophoric
90	Dark gray powder; pyrophoric

nearly solid amalgam. In experiments in which some hydride amalgams were being compressed in steel dies at high pressures, mercury almost free of uranium was extruded from the crevices (*2*).

Radiochemical properties. Neutron-bombarded uranium, containing radioactive xenon (*3*), was converted to the hydride in a flask attached to a cylinder holding an aluminum-walled Geiger-Müller counter tube; during this process, less than 1% of the radioxenon escaped. Mercury was introduced, forming a liquid amalgam with the hydride; again less than 1% of the xenon was released, as shown by the counter. Heating the amalgam to 200–225° caused only very little more of the xenon to be liberated. It was necessary to dissolve the mixture completely in order to effect complete recovery of the radioactive rare gas. This was in contrast to the behavior of uranium metal amalgam, from which the radioxenon was rapidly released upon boiling.

Hydrogen-deuterium exchange in uranium hydride and deuteride amalgams. In connection with the attempts to separate deuterium from hydrogen employing uranium hydride (*4*), experiments were run in which the rate of exchange of hydrogen with the deuterium in uranium deuteride amalgam was measured. Hydrogen was admitted to a flask holding the deuteride amalgam at 350°, and samples of the gas were removed periodically for analysis on the gas density balance. It was found that after 5 minutes the hydrogen contained 0.2% deuterium, after 15 minutes 2.7%, and after 2 hours 10.3%. The experiment was repeated with comparable results using a deuterium atmosphere over uranium hydride amalgam.

The exchange of hydrogen for deuterium in uranium deuteride amalgam was exceedingly slow compared with the exchange in the unamalgamated deuteride. It is probable that the thermal decomposition of the uranium deuteride in mercury at 350° was a factor in the evolution of deuterium, and that no true reversible exchange took place because of the reaction of the metallic uranium released with mercury, which resulted in the formation of an intermetallic compound.

Chemical properties of uranium hydride amalgams. Exposure of the amalgams to air caused a fine brown powder to form on the surface of the preparation (*2*). Air was bubbled through an amalgam for 12 hours,

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during which time a large amount of the brown powder appeared. Enough heat was evolved during the aeration to maintain the temperature 6° above room temperature. The bulk of the mercury was removed, but its shiny surface was soon tarnished, and much more of the brown powder was formed on longer exposure to the air. Samples of the powder, which contained intimately admixed mercury, were analyzed for uranium and hydrogen by combustion. The results, expressed as hydrogen-uranium ratios, were 2.85 and 2.82, slightly less than in uranium hydride itself. The brown powder was thus principally uranium hydride; this was confirmed by an X-ray diffraction pattern, by its chemical properties, and by its thermal decomposition to uranium metal.

Uranium hydride amalgams were prepared and exposed to air, the weight increases being followed by periodic weighing. A 106 gm sample of 29% hydride amalgam gained oxygen at the rate of 1 mg per minute at the start, but the rate dropped rapidly. After three years, the rate gain was 1.7 mg per day, and the total increase corresponded to the oxidation of 75% of the uranium hydride to the oxide, U_3O_8. The rate of water formation upon aeration of a hydride amalgam was determined by weighing a drying tube through which the air passed after bubbling through the liquid amalgam (*5*). It was observed that the water, formed by oxidation of a small fraction of the hydride, was given off at about the same rate at which the hydride amalgam gained weight. Thus when uranium hydride was "precipitated" from mercury by the action of air, it was partially oxidized. This corresponded to a drop in the H/U ratio from 2.97 to about 2.83.

It is of interest to compare the aeration of uranium hydride amalgams with the similar treatment of uranium amalgams, formed, as previously mentioned, from powdered uranium and mercury. Such mixtures gained weight in air quite rapidly as a dark solid separated. The weight gain exceeded that corresponding to complete oxidation of the uranium alone to U_3O_8, suggesting that oxidation of the U-Hg intermetallic compounds gave oxides of both elements. Support for this conclusion was gained by leaching an oxidized sample with dilute hydrochloric acid, which dissolves HgO but not U_3O_8; the solution gave a strong test for mercury.

Water vapor was observed to form slowly a grayish-brown incrustation on uranium hydride amalgam. The solid which separated was found to consist principally of uranium hydride. Similarly, hydrogen sulfide caused separation of a dark powder (*6*), which proved to be mostly uranium hydride, but evidently contained some uranium sulfide as well, the sulfur content being about 0.6%.

A single attempt was made to reduce an organic compound with uranium hydride amalgam. Maleic anhydride was refluxed with a 25% hydride amalgam; a thick brown syrup resulted, very similar to the material formed without mercury present (*3*). Attempts to recover crystals from dioxane were fruitless.

Uranium hydride and metals other than mercury. In order to determine whether mercury was unique in its ability to wet uranium hydride, a sample was treated with a sodium-potassium alloy which was liquid at room temperature. The alloy appeared to wet the uranium hydride and form a composition of the same general appearance and character as the amalgams. Wood's metal was also tested by melting several grams with a little uranium hydride. On shaking the liquid with the powder, the alloy expanded rapidly, forming a spongy

mass which completely filled the flask. A similar effect was observed when tin was melted with uranium hydride. It is probable that the molten metals wetted the hydride, reacted with it, and formed intermetallic compounds of uranium, and that hydrogen was liberated from the interior of the semi-liquid mass.

Experimental

Preparation of uranium hydride amalgams. Uranium hydride was prepared in a flask to which was connected an inlet for introducing the desired amount of mercury. The mercury was then held either in a reservoir attached to a ground-glass joint in such a manner that rotation permitted the liquid to flow onto the hydride, or in a dropping funnel so that it could be run in by opening the stopcock. The mercury was added to the hydride at room temperature in an atmosphere of pure hydrogen, or in the evacuated apparatus.

Radiochemical properties. An apparatus was assembled which consisted of a flask with a side arm containing mercury, connections for hydrogen, and a connection through a stopcock to a cylinder holding a Geiger-Müller counter tube. The walls of the counter tube were of thin aluminum. After conversion to the hydride, the apparatus was tilted so that the mercury flowed into the reaction vessel, and formed the amalgam. The traces of gases evolved were swept over the counter tube by the use of a little argon as a carrier gas.

Hydrogen-deuterium exchange in uranium hydride and deuteride amalgams. A 25% uranium deuteride amalgam was prepared, and the system evacuated. Hydrogen was admitted until a pressure of 400 mm had been reached, and the temperature raised to 350°. Samples were withdrawn over 2 hours and analyzed with a gas density balance similar to that used by Stock and Ritter (7).

Chemical properties of uranium hydride amalgams. The amalgams were exposed to the air, admitting only a little air at a time at first, to lessen danger of ignition. The aeration was then completed by exposure in a beaker, or by bubbling air through the liquid. The brown powder was generally not pyrophoric, but on several occasions samples ignited unexpectedly.

The experiment determining the rate of water formation on aeration of an amalgam was conducted using 134 gm of 22% hydride amalgam in a flask equipped with a delivery tube leading under the surface of the mercury. A slow stream of air, dried by anhydrous magnesium perchlorate, was bubbled through the amalgam, filtered through fine glass wool to remove suspended particles, and passed through a drying tower. The tower was weighed over a 3-month period, after which it had gained a total of 97 mg.

To determine the effect of water vapor, an amalgam was exposed to purified hydrogen which had been bubbled through water. The effect of hydrogen sulfide was examined by admitting the pure gas to the amalgam. In each case the solids formed were removed and transferred in a carbon dioxide-filled dry box.

In the attempted reduction of maleic anhydride, 10 gm of uranium were converted to the hydride, amalgamated with 30 gm of mercury, and 1.8 gm of the anhydride were shaken in from a side arm. By means of a salt bath, the temperature was raised until the organic material began to boil; then the mixture was refluxed for 15 minutes. The entire operation was carried out in an atmosphere of hydrogen.

Uranium hydride and metals other than mercury. Sodium was melted with potassium under mineral oil and formed an alloy 40% in sodium. With apparatus similar to that used in forming amalgams, about 20 gm of the liquid

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were allowed to run upon 2 gm of uranium hydride. In the test with Wood's metal, a lump (17 gm) was suspended in the neck of a flask while uranium (5 gm) was converted to its hydride in the bulb (40 ml). After cooling, the metal was lowered into the flask, and was melted by gentle heating. The technique with tin was similar.

Discussion

The nature of uranium hydride amalgams. The observation that mercury relatively free of uranium could be filtered or pressed from uranium hydride amalgams indicated that the preparations were not true solutions. The concept was confirmed by the retention of radioxenon in the hydride after amalgamation; genuine dissolution of the hydride particles would certainly cause release of the inert gas. The formation of a dispersion in which each particle retained its own structure would account for the lack of a temperature change during preparation, and for the separation of products predominantly uranium hydride caused by the action of air, water, or hydrogen sulfide. Probably a surface effect was responsible for the amalgamation phenomenon, a protective layer of oxide sufficing to repel the mercury. The disposition of the hydride particles in the sodium-potassium alloy was presumably the same. The suspensions were possibly of a borderline colloidal nature. It is believed that the wetting of uranium hydride by mercury is another manifestation of its metallic character (4).

Summary

The formation of dispersion systems of uranium hydride and mercury was described. The systems were termed amalgams, although the evidence disclosed that the preparations were not true solutions or amalgams, but suspensions. The consistency of the amalgams as a function of concentration, the behavior of radioxenon in uranium hydride upon amalgamation, the exchange of hydrogen with the deuterium of uranium deuteride amalgams and *vice versa*, the chemical properties of the hydride amalgams, and the formation of related systems were discussed.

* * *

The authors wish to acknowledge the aid of Messrs. B. O. Ayers and R. W. Fisher, and of Dr. A. F. Voigt, for aid in the experimental work with uranium hydride amalgams.

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ERRATUM—"REP" UNIT

In the reports on the IRE-AIEE Instrumentation Conference appearing in the January, 1949, issue of NUCLEONICS, there appeared (on p. 44) in the discussion of the paper, "Biological Effects of Radiation and Health Protection," by G. Failla, a statement that the "rep" is a unit which is the same as the roentgen for X-rays but for the other particles represents the amount which will do the same biological damage as a roentgen of X-rays. Dr. Failla has pointed out that this actually is the definition of the "rem" (roentgen equivalent man). In his talk, Dr. Failla used the "rep" unit which he defines as follows: the dose of any ionising radiation at a given point in a tissue when the energy absorbed from the radiation is 83 ergs per gram of tissue.

Neutron Distributions in Elementary Diffusion Theory—II

The first part of this paper, which is presented in the interests of encouraging engineers to acquaint themselves with the problems of reactor design, was published in the February NUCLEONICS. Part I included the outline of the complete paper, together with a discussion of the mathematical formulation of diffusion problems and two useful relations concerning source distribution. It also covered solutions to the problems of the following forms of medium: 1) infinite medium with planar distributions; 2) infinite medium with spherical distributions; 3) semi-infinite medium; 4) slab of finite thickness and infinite extent; and 5) sphere. Here Part II, which is the concluding portion of the paper, offers solutions for four additional forms of medium; sphere with a concentric cavity; infinite "pile" of rectangular cross section; finite "pile" (parallelepiped); and cylinder. An index to the notations used in all solutions appears on page 67.

By PHILIP R. WALLACE

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6. SPHERE WITH CONCENTRIC SPHERICAL CAVITY

1. Thermal Neutrons

Suppose the cavity has radius a_1, and a source of strength Q is at its center. The thermal neutron density is then

$$\rho = \frac{Qr \sinh \dfrac{a-r}{L}}{4\pi\left[a_1 L \cosh \dfrac{a-a_1}{L} + L^2 \sinh \dfrac{a-a_1}{L}\right] r} \tag{6.1a}$$

The current over the outer boundary of the medium is

$$j(a) = \frac{Q}{4\pi\left[a_1 \cosh \dfrac{a-a_1}{L} + L \sinh \dfrac{a-a_1}{L}\right] a}$$

If the medium is infinite ($a \to \infty$) we have

$$\rho = \frac{Qre^{-\frac{(r-a_1)}{L}}}{4\pi L^2 r\left[1 + \dfrac{a_1}{L}\right]}.$$

Therefore, the effect of the cavity is to increase the effective strength of the source by a factor

$$\frac{e^{a_1/L}}{1 + \dfrac{a_1}{L}} > 1$$

[cf. equation (2.1a) in Part I of this paper].

In graphs (6.1a) and (6.1b) there are plotted ρ and $r^2\rho$ for an infinite medium with various sizes of cavity: ¼, ½, 1, 2 diffusion lengths, respectively.

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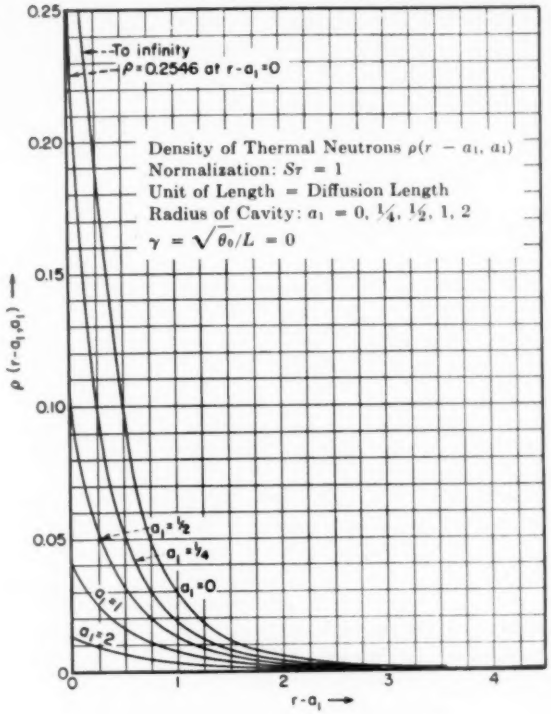
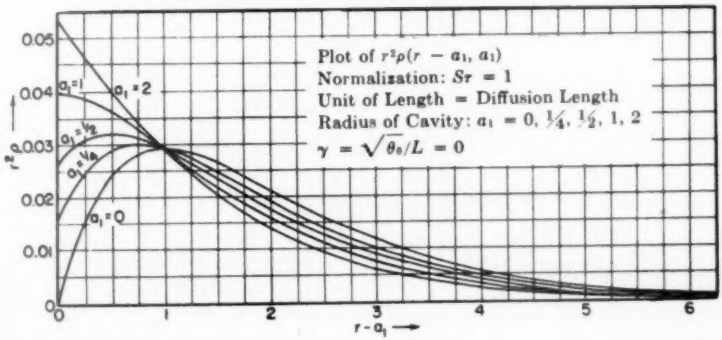
Graph 6.1a—Infinite medium with spherical cavity, point source of fast neutrons at its center



Graph 6.1b—Infinite medium with spherical cavity, point source of fast neutrons at its center



In the case of a shell source of radius r' $(a_1 < r' < a)$ the density is

$$\rho = \frac{Q\tau \sinh \frac{a-r'}{L}\left(a_1 \cosh \frac{r-a_1}{L} + L \sinh \frac{r-a_1}{L}\right)}{4\pi r r' L\left(a_1 \cosh \frac{a-a_1}{L} + L \sinh \frac{a-a_1}{L}\right)}, \qquad (r < r')$$

$$\rho = \frac{Q\tau\left(a_1 \cosh \frac{r'-a_1}{L} + L \sinh \frac{r'-a_1}{L}\right)\sinh \frac{a-r}{L}}{4\pi r r' L\left(a_1 \cosh \frac{a-a_1}{L} + L \sinh \frac{a-a_1}{L}\right)}, \qquad (r > r') \quad (6.1b)$$

If the medium is infinite, it becomes

$$\rho = \frac{Q\tau e^{-(r'-a_1)/L}}{4\pi(a_1+L)Lr'r}\left[a_1 \cosh \frac{r-a_1}{L} + L \sinh \frac{r-a_1}{L}\right], \qquad (r < r')$$

$$\rho = \frac{Q\tau\left[a_1 \cosh \frac{r'-a_1}{L} + L \sinh \frac{r'-a_1}{L}\right]}{4\pi(a_1+L)Lr'r} e^{-(r-a_1)/L} \qquad (r > r')$$

For a source distribution $q(r)$ we have, for the finite medium

$$\rho = \frac{\tau}{rL\left(a_1 \cosh \frac{a-a_1}{L} + L \sinh \frac{a-a_1}{L}\right)}\left\{\sinh \frac{a-r}{L}\int_{a_1}^{r} r'\left(a_1 \cosh \frac{r'-a_1}{L} + L \sinh \frac{r'-a_1}{L}\right) q(r')dr' + \left(a_1 \cosh \frac{r-a_1}{L} + L \sinh \frac{r-a_1}{L}\right)\int_{r}^{a} r' \sinh \frac{a-r'}{L} q(r')dr'\right\} \quad (6.1c)$$

and for the infinite medium this becomes

$$\rho = \frac{\tau e^{-(r-a_1)/L}}{(a_1+L)Lr}\int_{a_1}^{r} r'\left[a_1 \cosh \frac{r'-a_1}{L} + L \sinh \frac{r'-a_1}{L}\right] q(r')dr' + \frac{\tau}{(a_1+L)Lr}\left[a_1 \cosh \frac{r-a_1}{L} + L \sinh \frac{r-a_1}{L}\right]\int_{r}^{\infty} r' e^{-(r'-a_1)/L} q(r')dr'$$

2. Fast Neutrons

For a point source of fast neutrons of strength S at the center of a cavity in a concentric spherical medium we have

$$X = \frac{S}{2\pi r}\sum_{m=1}^{\infty} \frac{(-1)^{m+1}\alpha_m \sqrt{1 + a_1^2\alpha_m^2}}{a + (a - a_1)a_1^2\alpha_m^2} \sin \alpha_m(a - r)e^{-\alpha_m^2\theta} \qquad (6.2a)$$

where the quantities α_m are roots of the transcendental equation

$$\tan \alpha(a - a_1) = -a_1\alpha$$

In the case in which the medium is infinite, the solution has the form

$$X = \frac{Se^{-\frac{(r-a_1)^2}{4\theta}}}{4a_1 r\sqrt{\pi^3\theta}}\left\{1 - \frac{\sqrt{\pi\theta}}{a_1} e^{\left(\frac{r-a_1}{2\sqrt{\theta}} + \frac{\sqrt{\theta}}{a_1}\right)^2}\left[1 - \operatorname{erf}\left(\frac{r-a_1}{2\sqrt{\theta}} + \frac{\sqrt{\theta}}{a_1}\right)\right]\right\}$$

In graphs (6.2a) and (6.2b), X and r^2X are plotted for infinite medium with various radii of cavity.

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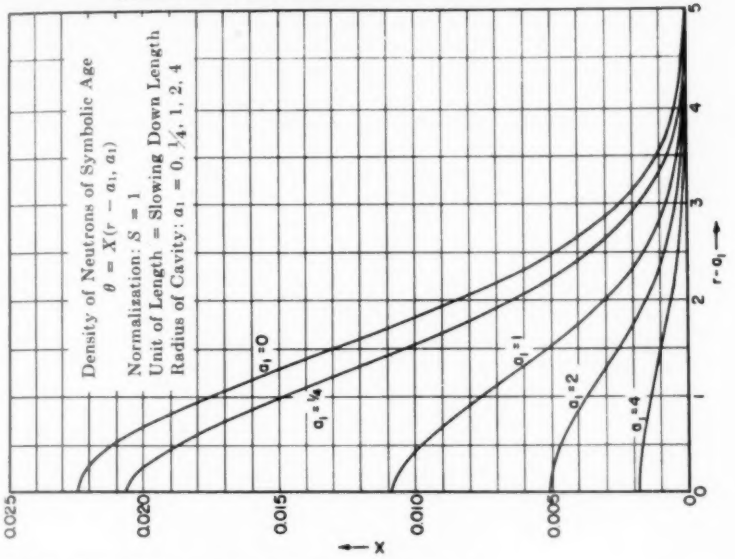
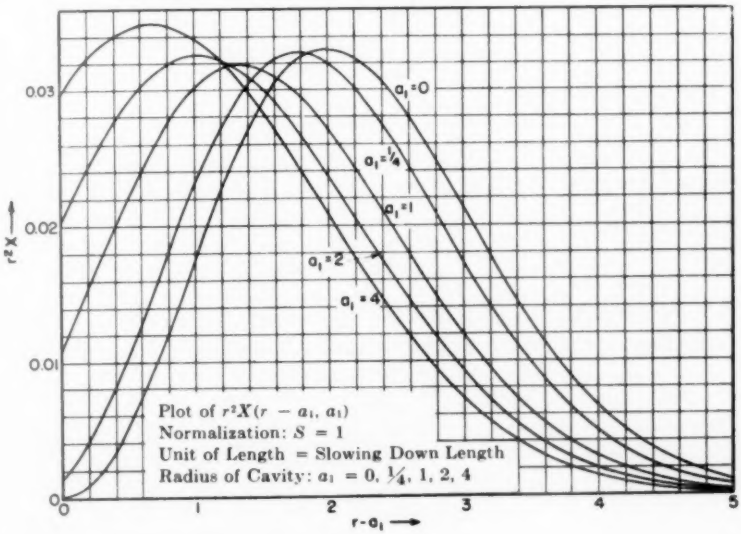
Graph 6.2a—Infinite medium with spherical cavity, point source of fast neutrons at its center



Graph 6.2b—Infinite medium with spherical cavity, point source of fast neutrons at its center



3. General Problem

The thermal neutron density due to a fast neutron point source of strength S is

$$\rho = \frac{\tau S}{2\pi r} \sum_{m=1}^{\infty} \frac{(-1)^{m+1} \alpha_m \sqrt{1 + a_1^2 \alpha_m^2}\, e^{-\alpha_m^2 \theta_0}}{[a + (a - a_1)a_1^2\alpha_m^2](1 + \alpha_m^2 L^2)} \sin \alpha_m (a - r). \qquad (6.3a)$$

In the case in which the medium is infinite, the solution has the form

$$\rho = \frac{S\tau e^{\frac{\theta_0}{a_1^2}} e^{\frac{r-a_1}{a_1}}}{4\pi r(L^2 - a_1^2)} \left[1 - \operatorname{erf}\left(\frac{r - a_1}{2\sqrt{\theta_0}} + \frac{\sqrt{\theta_0}}{a_1} \right) \right] + \frac{S\tau e^{\frac{\theta_0}{L^2}}}{8\pi r L} \left\{ \frac{e^{\frac{r-a_1}{L}}}{a_1 - L} \left[1 - \operatorname{erf}\left(\frac{r - a_1}{2\sqrt{\theta_0}} + \frac{\sqrt{\theta_0}}{L} \right) \right] + \frac{e^{-\frac{r-a_1}{L}}}{a_1 + L} \left[1 + \operatorname{erf}\left(\frac{r - a_1}{2\sqrt{\theta_0}} - \frac{\sqrt{\theta_0}}{L} \right) \right] \right\}$$

The following graphs are included for an infinite medium with $a = 0$, ¼, ½, 1, 2 migration lengths:

Graph	*Plot of*	γ	*Graph*	*Plot of*	γ	*Graph*	*Plot of*	γ
6.3a	ρ	¼	6.3e	$r^2\rho$	¼	6.3i	$4\pi \int_{a_1}^{r} r^2 \rho dr$	¼
6.3b		½	6.3f		½	6.3j		½
6.3c		1	6.3g		1	6.3k		1
6.3d		2	6.3h		2	6.3l		2

7. INFINITE PILE

1. Thermal Neutrons

We consider an infinite column of rectangular cross section, the cross-sectional dimensions being a_1 and a_2. The pile is then bounded by $x = 0$, a_1 and $y = 0$, a_2.

We shall designate our solutions throughout the sections on piles by giving the Fourier coefficients of the distributions. For instance, the thermal neutron density is of the form

$$\rho = \sum_{l,m=1}^{\infty} \rho_{lm} \sin \frac{l\pi x}{a_1} \sin \frac{m\pi y}{a_2}$$

ρ_{lm} will sometimes be designated, for convenience, as $\tilde{\rho}$.

We have, then, for a point source at x', y', z'

$$\tilde{\rho} = \frac{2\tau Q}{L\omega_{lm} a_1 a_2} \sin \frac{l\pi x'}{a_1} \sin \frac{m\pi y'}{a_2} e^{-\omega_{lm}|z - z'|/L} \qquad (7.1a)$$

where

$$\omega_{lm} = \sqrt{1 + \beta_{lm}^2 L^2}$$

and

$$\beta_{lm}^2 = \pi^2 \left(\frac{l^2}{a_1^2} + \frac{m^2}{a_2^2} \right)$$

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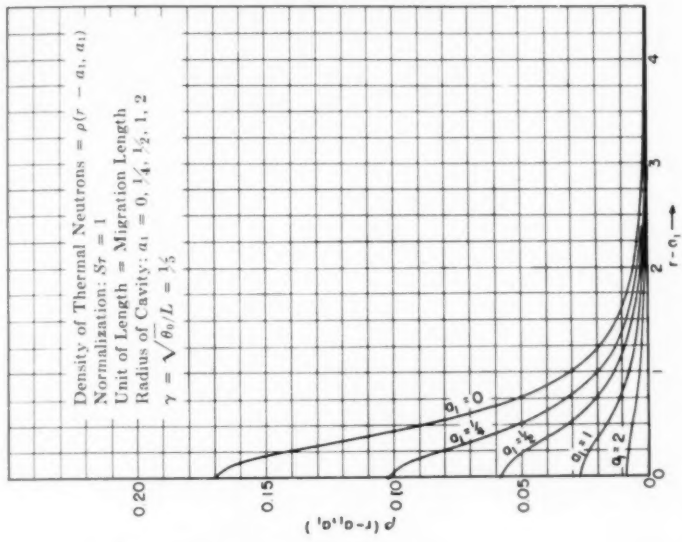
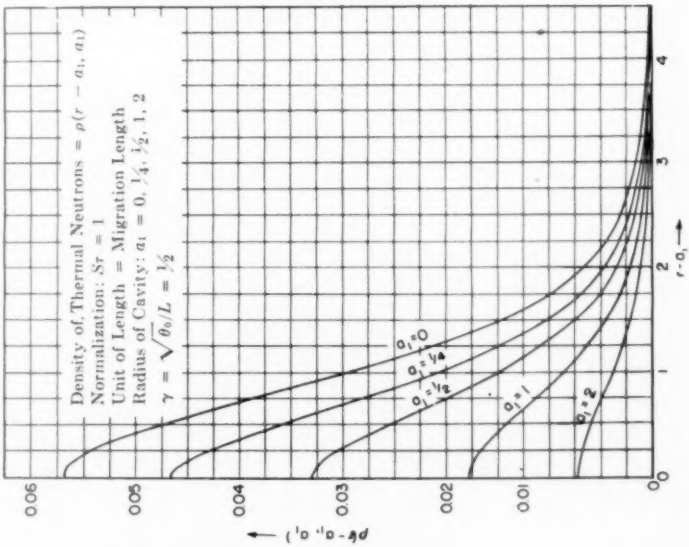
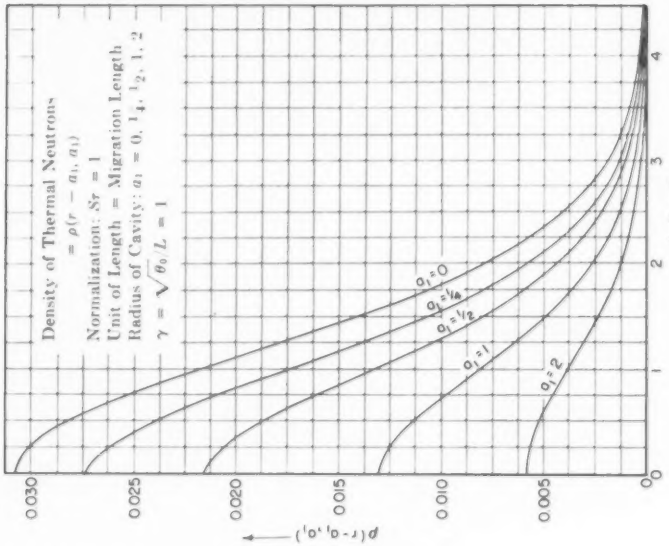
Graph 6.3a—Infinite medium with spherical cavity, point source of fast neutrons at its center


Density of Thermal Neutrons = $\rho(r - a_1, a_1)$
Normalization: $Sr = 1$
Unit of Length = Migration Length
Radius of Cavity: $a_1 = 0, \frac{1}{4}, \frac{1}{2}, 1, 2$
$\gamma = \sqrt{\theta_0/L} = \frac{1}{2}$
$a_1 = 0$
$a_1 = \frac{1}{4}$
$a_1 = \frac{1}{2}$
$a_1 = 1$
$a_1 = 2$
$r - a_1$
$\rho(r-a_1, a_1)$

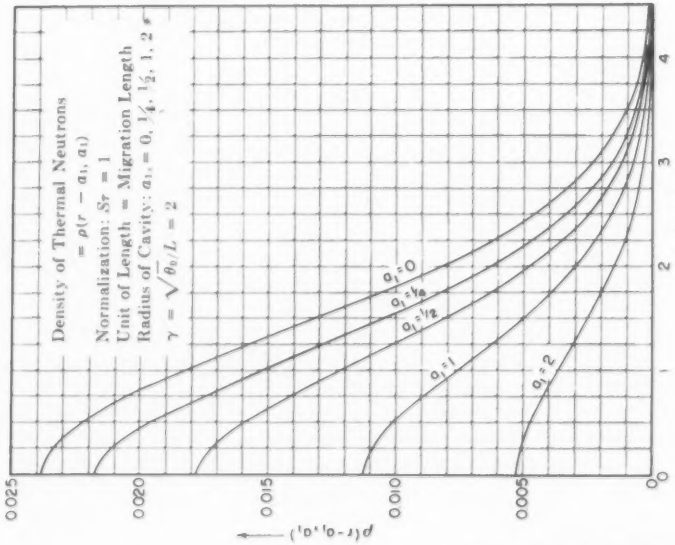
Graph 6.3b—Infinite medium with spherical cavity, point source of fast neutrons at its center


Density of Thermal Neutrons = $\rho(r - a_1, a_1)$
Normalization: $Sr = 1$
Unit of Length = Migration Length
Radius of Cavity: $a_1 = 0, \frac{1}{4}, \frac{1}{2}, 1, 2$
$\gamma = \sqrt{\theta_0/L} = \frac{1}{2}$
$a_1 = 0$
$a_1 = \frac{1}{4}$
$a_1 = \frac{1}{2}$
$a_1 = 1$
$a_1 = 2$
$r - a_1$
$\rho(r-a_1, a_1)$

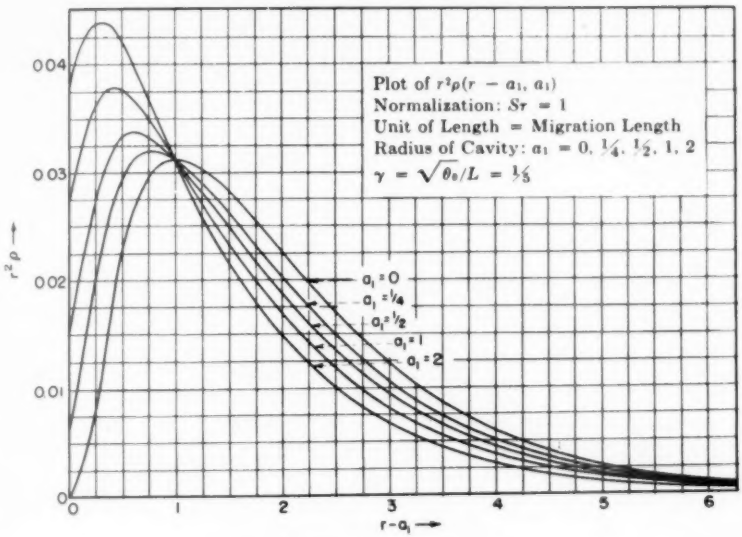
Graph 6.3c—Infinite medium with spherical cavity, point source of fast neutrons at its center



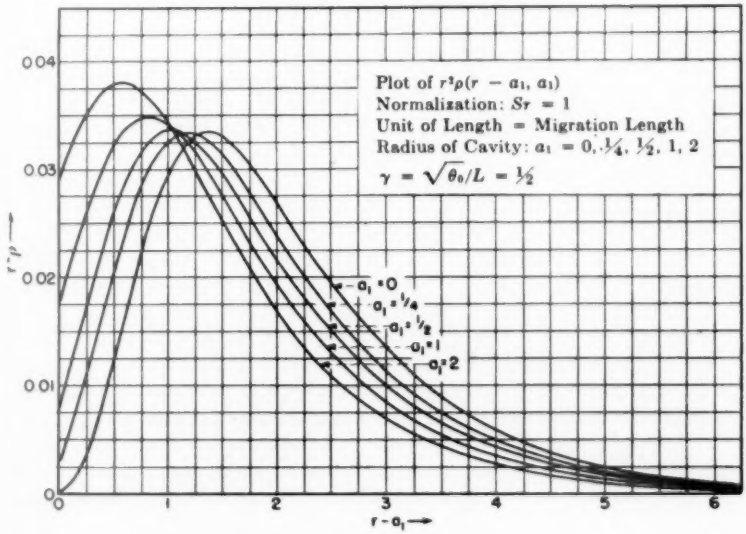
Graph 6.3d—Infinite medium with spherical cavity, point source of fast neutrons at its center



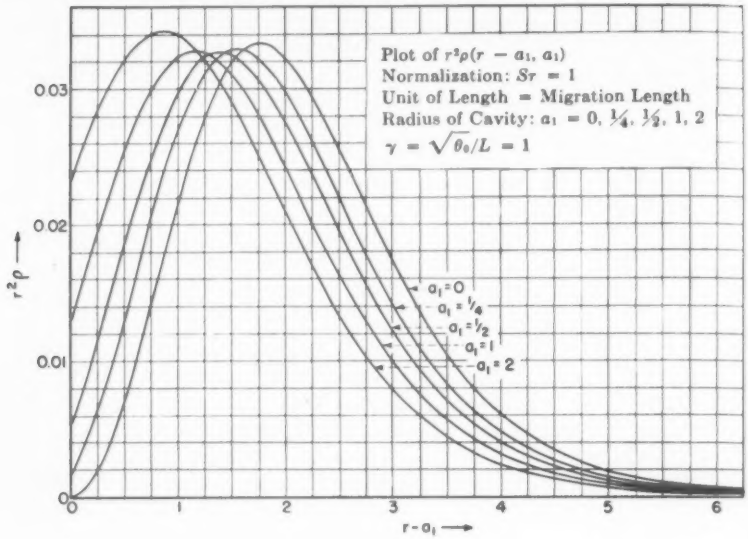
Graph 6.3e— Infinite medium with spherical cavity, point source of fast neutrons at its center



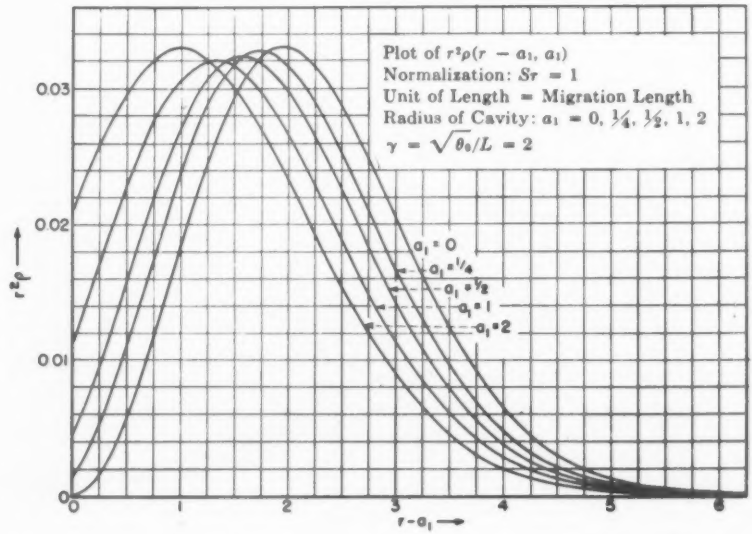
Graph 6.3f— Infinite medium with spherical cavity, point source of fast neutrons at its center



Graph 6.3g— Infinite medium with spherical cavity, point source of fast neutrons at its center



Graph 6.3h— Infinite medium with spherical cavity, point source of fast neutrons at its center



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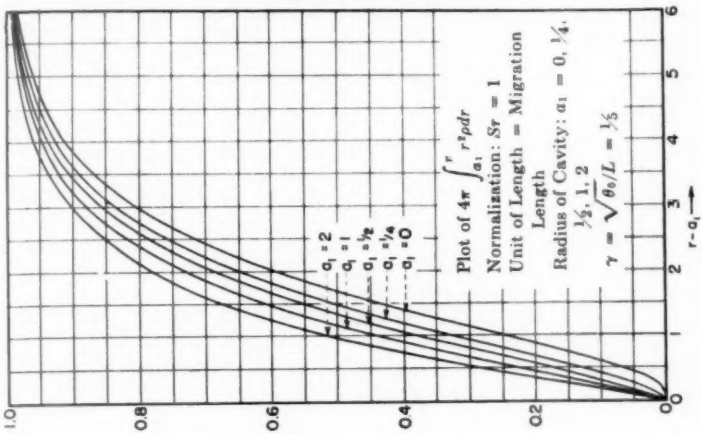
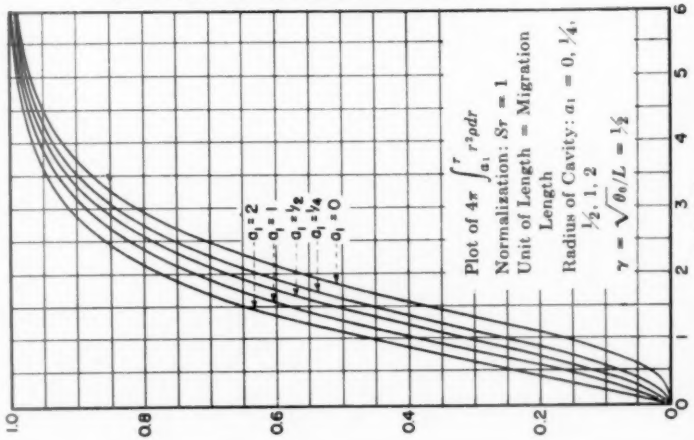
Graph 6.3i—Infinite medium with spherical cavity, point source of fast neutrons at its center


Plot of $4\pi \int_{a_1}^{r} r^2 \rho dr$
Normalization: $Sr = 1$
Unit of Length = Migration Length
Radius of Cavity: $a_1 = 0, \frac{1}{4}, \frac{1}{2}, 1, 2$
$\gamma = \sqrt{\theta_0}/L = \frac{1}{2}$
$a_1 = 2$
$a_1 = 1$
$a_1 = \frac{1}{2}$
$a_1 = \frac{1}{4}$
$a_1 = 0$
$r - a_1$

Graph 6.3j—Infinite medium with spherical cavity, point source of fast neutrons at its center


Plot of $4\pi \int_{a_1}^{r} r^2 \rho dr$
Normalization: $Sr = 1$
Unit of Length = Migration Length
Radius of Cavity: $a_1 = 0, \frac{1}{4}, \frac{1}{2}, 1, 2$
$\gamma = \sqrt{\theta_0}/L = \frac{1}{2}$
$a_1 = 2$
$a_1 = 1$
$a_1 = \frac{1}{2}$
$a_1 = \frac{1}{4}$
$a_1 = 0$
$r - a_1$

Graph 6.3k—Infinite medium with spherical cavity, point source of fast neutrons at its center

Graph 6.3l—Infinite medium with spherical cavity, point source of fast neutrons at its center

In the case of a plane distribution $q(z)$

$$\tilde{\rho}(z) = \frac{8\tau}{\pi^2 l m L \omega_{lm}} \int_{-\infty}^{\infty} e^{-\omega_{lm}|z-z'|/L}\, q(z')dz'$$

$$\text{when } l = 2l' + 1, \quad m = 2m' + 1 \qquad (7.1b)$$

$$= 0 \text{ otherwise}$$

while for a general source distribution $q(x, y, z)$

$$\tilde{\rho} = \frac{\tau}{2L\omega} \int_{-\infty}^{\infty} e^{-\omega|z-z'|/L}\, \tilde{q}(z')dz' \qquad (7.1c)$$

where $\tilde{q} = q_{lm}$ is the Fourier coefficient in the expansion of the source function as a function of x and y.

2. Fast Neutrons

The fast neutron distribution due to point source of strength S at x', y', z' is given by

$$X_{lm} = \frac{4S}{a_1 a_2} \frac{e^{-\left(\frac{l^2}{a_1^2}+\frac{m^2}{a_2^2}\right)\pi^2\theta}}{\sqrt{4\pi\theta}} \sin\frac{l\pi x'}{a_1} \sin\frac{m\pi y'}{a_2}\, e^{-\frac{(z-z')^2}{4\theta}} \qquad (7.2a)$$

or, in the alternative form which converges rapidly for a large system,

$$X = \frac{Se^{-\frac{(z-z')^2}{4\theta}}}{(4\pi\theta)^{3/2}} \sum_{l,m=-\infty}^{\infty} \left[e^{-\frac{(x-x'+2la_1)^2}{4\theta}} - e^{-\frac{(x+x'+2la_1)^2}{4\theta}} \right] \left[e^{-\frac{(y-y'+2ma_2)^2}{4\theta}} - e^{-\frac{(y+y'+2ma_2)^2}{4\theta}} \right] \qquad (7.2a')$$

In the case of a general source distribution $s(x,y,z)$ we have

$$\tilde{X} = \frac{e^{-\beta^2\theta}}{\sqrt{4\pi\theta}} \int_{-\infty}^{\infty} e^{-\frac{(z-z')^2}{4\theta}}\, \tilde{s}(z')dz' \qquad (7.2c)$$

where $\tilde{s}(z) = s_{lm}(z)$ is the Fourier coefficient of s considered as a function of x and y.

3. General Problem

The distribution of thermal neutrons due to a point source of fast neutrons of strength S at x',y',z' is given by

$$\rho = \frac{S\tau e^{\frac{\theta_0}{L^2}}}{a_1 a_2 \omega L} \sin\frac{l\pi x'}{a_1} \sin\frac{m\pi y'}{a_2} \left\{ e^{-\frac{\omega(z-z')}{L}} \left[1 - \operatorname{erf}\left(\frac{\sqrt{\theta_0\omega}}{L} - \frac{z-z'}{2\sqrt{\theta_0}} \right) \right] + e^{\frac{\omega(z-z')}{L}} \left[1 - \left(\operatorname{erf}\frac{\sqrt{\theta_0\omega}}{L} + \frac{z-z'}{2\sqrt{\theta_0}} \right) \right] \right\} \qquad (7.3a)$$

where ω is defined as in (7.1)

The solutions for general plane and space distributions may be written down by superposition of point sources. Thus, for a plane source at $Z = Z'$, we have

$$\tilde{\rho} = \frac{\tilde{s}_0 \tau e^{\frac{\theta_0}{L^2}}}{4L\omega} \left\{ e^{-\omega\frac{z-z'}{L}} \left[1 + \operatorname{erf}\left(\frac{z-z'}{2\sqrt{\theta_0}} - \frac{\sqrt{\theta_0 \omega}}{L} \right) \right] \right.$$

$$\left. + e^{\omega\frac{z-z'}{L}} \left[1 - \operatorname{erf}\left(\frac{z-z'}{2\sqrt{\theta_0}} + \frac{\sqrt{\theta_0 \omega}}{L} \right) \right] \right\} \quad (7.3b)$$

where $\tilde{s}_0$ is the Fourier expansion coefficient for the source function $s_0(x,y)$.

4. Multiplication

We shall give here only the solution for a non-uniform plane source in the plane $z = 0$. A point source is, of course, a special case of this. The solution for a general source distribution may be obtained by superposition. The solution is given by

$$\tilde{\rho} = \frac{1}{2} \tilde{s}_0 \tau e^{-\beta^2 \theta_0} \sum_{n=-\infty}^{\infty} \frac{e^{\alpha_n^2 \theta_0} e^{-\alpha_n z}}{\alpha_n [L^2 + k\theta_0 e^{-(\beta^2 - \alpha_n^2)\theta_0}]}. \quad (7.4a)$$

Here the quantities α_n are the (complex) roots of the transcendental equation

$$[1 + (\beta^2 - \alpha^2)L^2] e^{(\beta^2 - \alpha^2)\theta_0} = k$$

If we put

$$\gamma^2 [1 + (\beta^2 - \alpha^2)L^2] = p = x + iy$$

so that

$$\alpha^2 = \beta^2 + \frac{1}{L_e^2} (\gamma^2 - p)$$

the solutions for p may be read off the graph (A.1) from section (1.4) in Part I of this paper. At sufficiently large distances from the source (a few migration lengths), the α_0 term will predominate. For k near unity,

$$\alpha_0^2 = \beta^2 - \frac{k-1}{L_0^2}$$

8. FINITE PILE

1. Thermal Neutrons

We consider a finite (rectangular) pile whose sides are defined by $x = 0$, a_1; $y = 0$, a_2; $z = 0$, a_3. Again we may introduce Fourier expansions in x and y; the solution is then defined by the Fourier components $\rho_{lm} = \tilde{\rho}$. In the case of a point source at x', y', z'

$$\left.\begin{aligned} \tilde{\rho} &= \frac{4\tau Q}{a_1 a_2 \omega L} \sin\frac{l\pi x'}{a_1} \sin\frac{m\pi y'}{a_2} \frac{\sinh \omega z'/L}{\sinh \omega \frac{a_3}{L}} \sinh \omega \frac{a_3 - z}{L} \qquad (z > z') \\ \tilde{\rho} &= \frac{4\tau Q}{a_1 a_2 \omega L} \sin\frac{l\pi x'}{a_1} \sin\frac{m\pi y'}{a_2} \frac{\sinh \omega \frac{a_3 - z'}{L}}{\sinh \omega \frac{a_3}{L}} \sinh \frac{\omega z}{L} \qquad (z < z') \end{aligned}\right\} \quad (8.1a)$$

For a plane source $q_0(x,y)$

$$\tilde{\rho} = \frac{\tau \tilde{q}_0}{L\omega} \frac{\sinh \omega \dfrac{z'}{L}}{\sinh \omega \dfrac{a_3}{L}} \sinh \omega \frac{a_3 - z}{L} \qquad (z > z')$$

$$\tilde{\rho} = \frac{\tau q_0}{L\omega} \frac{\sinh \omega \dfrac{a_3 - z'}{L}}{\sinh \omega \dfrac{a_3}{L}} \sinh \omega \frac{z}{L} \qquad (z < z') \qquad (8.1b)$$

The first term in the Fourier expansion ($l = m = 1$) will give a good representation of the solution at distances from the source plane $\gg L/(\omega_{12} - \omega_{11})$.

In the case of a general source distribution $q(x,y,z)$

$$\tilde{\rho} = \frac{\tau}{L\omega} \frac{1}{\sinh \omega \dfrac{a_3}{L}} \left[\sinh \omega \frac{a_3 - z}{L} \int_0^z \sinh \omega \frac{z'}{L} \tilde{q}(z')dz' + \sinh \frac{\omega z}{L} \int_z^{a_3} \sinh \omega \frac{a_3 - z'}{L} \tilde{q}(z')dz' \right] \qquad (8.1c)$$

If there are no sources and the density is given at the end $z = 0$, i.e.,

$$\rho(x,y,0) = \rho_0(x,y)$$

the solution is

$$\tilde{\rho} = \tilde{\rho}_0 \frac{\sinh \dfrac{\omega}{L}(a_3 - z)}{\sinh \dfrac{\omega}{L} a_3}$$

2. Fast Neutrons

If there is a point source of fast neutrons S at x', y', z'

$$X = \frac{8S}{a_1 a_2 a_3} \sum_{l,m,n=1}^{\infty} e^{-\left(\frac{l^2}{a_1^2} + \frac{m^2}{a_2^2} + \frac{n^2}{a_3^2}\right)\pi^2\theta} \sin \frac{l\pi x'}{a_1} \sin \frac{m\pi y'}{a_2} \sin \frac{n\pi z'}{a_3} \sin \frac{l\pi x}{a_1} \sin \frac{m\pi y}{a_2} \sin \frac{n\pi z}{a_3} \qquad (8.2a)$$

An alternative form may be written most simply for a coordinate system whose origin is at the center of the pile. The distribution is

$$X = \frac{S}{(4\pi\theta)^{3/2}} \sum_{l,m,n=-\infty}^{\infty} (-1)^{l+m+n} e^{-\frac{\bar{r}_{lmn}^2}{4\theta}},$$

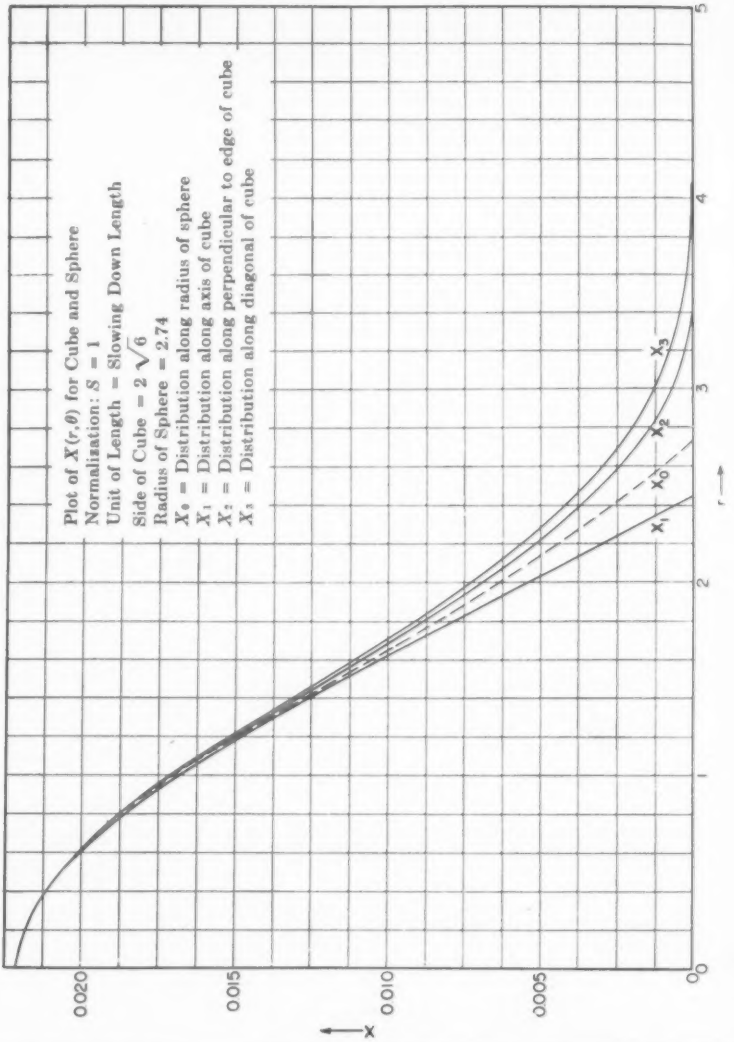
where $\bar{r}_{lmn}^2 = [\bar{x} - (-1)^l \bar{x}' + la_1]^2 + [\bar{y} - (-1)^m \bar{y}' + ma_2]^2 + [\bar{z} - (-1)^n \bar{z}' + na_3]^2 \qquad (8.2a')$

Graph (8.2a) permits a comparison of the distributions in a cube and a sphere. The comparison is made for a sphere of such size that the density is the same at its center as at the center of the cube.

In the case of a non-uniform plane source distribution $s_0(x,y)$

$$\tilde{X} = \frac{2}{a_3} \sum_{n=1}^{\infty} \tilde{s}_0 e^{-\left(\frac{l^2}{a_1^2} + \frac{m^2}{a_2^2} + \frac{n^2}{a_3^2}\right)\pi^2\theta} \sin \frac{n\pi z'}{a_3} \sin \frac{n\pi z}{a_3} \qquad (8.2b)$$

Graph 8.2a—Sphere and cube, point source



or, alternatively, with the origin at the center of the pile

$$\bar{X} = \frac{\bar{s}_0 e^{-\beta_0^2 \theta}}{\sqrt{4\pi\theta}} \sum_{n=-\infty}^{\infty} (-1)^n e^{-\frac{(\bar{s}-\bar{s}'+na_2)^2}{4\theta}} \qquad (8.2b')$$

Finally, for a general source distribution

$$X = \sum_{l,m,n=1}^{\infty} s_{lmn}\, e^{-\left(\frac{l^2}{a_1^2}+\frac{m^2}{a_2^2}+\frac{n^2}{a_3^2}\right)\pi^2\theta} \sin\frac{l\pi x}{a_1} \sin\frac{m\pi y}{a_2} \sin\frac{n\pi z}{a_3} \qquad (8.2c)$$

where s_{lmn} is the coefficient in the expansion of $s(x,y,z)$, the source function, in a Fourier series in all three variables. An alternative form which is more rapidly convergent for a large is

$$X = \frac{1}{(4\pi\theta)^{3/2}} \sum_{l,m,n=-\infty}^{\infty} (-1)^{l+m+n} \int_0^{a_1} dx' \int_0^{a_2} dy' \int_0^{a_3} dz' \cdot s(x',y',z') e^{-\frac{\bar{r}_{lmn}^2}{4\theta}} \qquad (8.2c')$$

where $\bar{r}_{lmn}$ is as in (8.2a'), the origin again being taken at the center of the pile.

3. General Problem

The thermal neutron distribution due to a point source of fast neutrons of strength S at (x',y',z') is given by

$$\rho_{lmn} = \frac{8Sre^{-\left(\frac{l^2}{a_1^2}+\frac{m^2}{a_2^2}+\frac{n^2}{a_3^2}\right)\pi^2\theta_0}}{a_1a_2a_3\left[1+\pi^2L^2\left(\frac{l^2}{a_1^2}+\frac{m^2}{a_2^2}+\frac{n^2}{a_3^2}\right)\right]} \sin\frac{l\pi x'}{a_1} \sin\frac{m\pi y'}{a_2} \sin\frac{n\pi z'}{a_3} \qquad (8.3a)$$

or, for the coordinate system with origin at the center of the pile

$$\rho = \frac{\tau S}{8\pi L^2} \sum_{l,m,n=-\infty}^{\infty} (-1)^{l+m+n} \frac{1}{\bar{r}_{lmn}} \left\{ e^{-\frac{\bar{r}_{lmn}}{L}} \left[1 - \operatorname{erf}\left(\frac{\sqrt{\theta_0}}{L} - \frac{\bar{r}_{lmn}}{2\sqrt{\theta_0}}\right)\right] - e^{\frac{\bar{r}_{lmn}}{L}} \left[1 - \operatorname{erf}\left(\frac{\sqrt{\theta_0}}{L} + \frac{\bar{r}_{lmn}}{2\sqrt{\theta_0}}\right)\right]\right\} \qquad (8.3a')$$

In the case of a plane source $s_0(x,y)$ in the plane $z = z'$

$$\rho = \sum_{l,m,n=1}^{\infty} \frac{2\tau\, s_{0lm}\, e^{-\left(\frac{l^2}{a_1^2}+\frac{m^2}{a_2^2}+\frac{n^2}{a_3^2}\right)\pi^2\theta_0}}{a_3\left[1+\pi^2L^2\left(\frac{l^2}{a_1^2}+\frac{m^2}{a_2^2}+\frac{n^2}{a_3^2}\right)\right]} \sin\frac{n\pi z'}{a_3} \sin\frac{l\pi x}{a_1} \sin\frac{m\pi y}{a_2} \sin\frac{n\pi z}{a_3} \qquad (8.3b)$$

or

$$\bar{\rho} = \frac{\bar{s}_0\tau e^{\frac{\theta_0}{L^2}}}{4L\omega} \sum_{n=-\infty}^{\infty} (-1)^n \left\{ e^{-\frac{\omega[\bar{z}-(-1)^n\bar{z}'+na_3]}{L}} \left[1 - \operatorname{erf}\left(\frac{\omega\sqrt{\theta_0}}{L} - \frac{\bar{z}-(-1)^n\bar{z}'+na_3}{2\sqrt{\theta_0}}\right)\right] + e^{\frac{\omega[\bar{z}-(-1)^n\bar{z}'+na_3]}{L}} \left[1 - \operatorname{erf}\left(\frac{\omega\sqrt{\theta_0}}{L} + \frac{\bar{z}-(-1)^n\bar{z}'+na_3}{2\sqrt{\theta_0}}\right)\right]\right\} \qquad (8.3b')$$

As usual, bars indicate coordinates measured from the center of the pile.

For a general source distribution $s(x,y,z)$

$$\rho_{lmn} = \frac{\tau e^{-\left(\frac{l^2}{a_1^2}+\frac{m^2}{a_2^2}+\frac{n^2}{a_3^2}\right)\pi^2\theta_0}}{1+\pi^2L^2\left(\frac{l^2}{a_1^2}+\frac{m^2}{a_2^2}+\frac{n^2}{a_3^2}\right)} s_{lmn} \tag{8.3c}$$

4. Multiplication

If there is a point source S of fast neutrons at (x',y',z')

$$\rho = \frac{8S\tau}{a_1a_2a_3}\sum_{l,m,n=1}^{\infty} \frac{\sin\frac{l\pi x'}{a_1}\sin\frac{m\pi y'}{a_2}\sin\frac{n\pi z'}{a_3}}{\left[\left(\frac{l^2}{a_1}+\frac{m^2}{a_2}+\frac{n^2}{a_3}\right)\pi^2L^2+1\right]e^{\left(\frac{l^2}{a_1^2}+\frac{m^2}{a_2^2}+\frac{n^2}{a_3^2}\right)\pi^2\theta_0}-k} \sin\frac{l\pi x}{a_1}\sin\frac{m\pi y}{a_2}\sin\frac{n\pi z}{a_3} \tag{8.4a}$$

$$\text{or } \rho = \sum_{l,m,n=-\infty}^{\infty} (-1)^{l+m+n}F(x-(-1)^lx'+la_1,\ y-(-1)^my'+ma_2,\ z-(-1)^nz'+na_3) \tag{8.4a'}$$

where $F(x-\bar{\xi},\ y-\bar{\eta},\ z-\bar{\zeta})$ is the solution for ρ in an *infinite* medium due to a point source at (ξ,η,ζ). (See 2.4a in Part I of this paper).

For a plane source $s_0(x,y)$ in the plane $z = z'$

$$\rho = \frac{\tau}{a_3}\sum_{l,m,n=1}^{\infty} \frac{s_{0lm}\sin\frac{n\pi z'}{a_3}}{\left[\left(\frac{l^2}{a_1^2}+\frac{m^2}{a_2^2}+\frac{n^2}{a_3^2}\right)\pi^2L^2+1\right]e^{\left(\frac{l^2}{a_1^2}+\frac{m^2}{a_2^2}+\frac{n^2}{a_3^2}\right)\pi^2\theta_0}-k} \sin\frac{l\pi x}{a_1}\sin\frac{m\pi y}{a_2}\sin\frac{n\pi z}{a_3} \tag{8.4b}$$

$$\text{or} \quad \rho = \frac{\bar{s}_0\tau e^{-\beta^2\theta_0}}{2}\sum_{n=-\infty}^{\infty} \frac{e^{\alpha_n{}^2\theta_0}[\cosh\alpha_n(a_3-|z-z'|)-\cosh\alpha_n(a_3-|z+z'|)]}{[L^2+k\theta_0e^{-(\beta^2-\alpha_n{}^2)\theta_0}]\alpha_n\sinh\alpha_na_3}, \qquad (k<(1+\beta^2L^2)e^{\beta^2\theta_0}) \tag{8.4b'}$$

where the quantities α_n are as in (7.4).

Finally, for an arbitrary source distribution we have a thermal neutron density

$$\rho = \tau\sum_{l,m,n=1}^{\infty} \frac{s_{lmn}}{\left[\left(\frac{l^2}{a_1^2}+\frac{m^2}{a_2^2}+\frac{n^2}{a_3^2}\right)\pi^2L^2+1\right]e^{\left(\frac{l^2}{a_1^2}+\frac{m^2}{a_2^2}+\frac{n^2}{a_3^2}\right)\pi^2\theta_0}-k} \sin\frac{l\pi x}{a_1}\sin\frac{m\pi y}{a_2}\sin\frac{n\pi z}{a_3} \tag{8.4c}$$

Critical conditions are determined by the equation

$$k = \left[\left(\frac{1}{a_1^2}+\frac{1}{a_2^2}+\frac{1}{a_3^2}\right)\pi^2L^2+1\right]e^{\left(\frac{1}{a_1^2}+\frac{1}{a_2^2}+\frac{1}{a_3^2}\right)\pi^2\theta_0}$$

If we put

$$\frac{1}{a} = \sqrt{\frac{1}{a_1^2} + \frac{1}{a_2^2} + \frac{1}{a_3^2}}$$

the critical value of a is given by

$$a = \frac{L_0}{\sqrt{k-1}} \{1 + \eta(\gamma, k-1)\}$$

where η is as defined in (4.4), etc. The neutron distribution under critical conditions is

$$\rho_{\text{crit}} = \rho_{111} \sin\frac{\pi x}{a_1} \sin\frac{\pi y}{a_2} \sin\frac{\pi z}{a_3}$$

$$X_{\text{crit}} = X_{111}\, e^{-\left(\frac{1}{a_1^2}+\frac{1}{a_2^2}+\frac{1}{a_3^2}\right)\pi^2\theta} \sin\frac{\pi x}{a_1} \sin\frac{\pi y}{a_2} \sin\frac{\pi z}{a_3}$$

where

$$X_{111} = \frac{k}{\tau}\rho_{111}.$$

9. CYLINDRICAL PILE

1. Thermal Neutrons

The thermal neutron density may be expanded in a series of the form

$$\rho(R,\phi,z) = \sum_{\substack{l=0 \\ m=1}}^{\infty} (\rho_{lm}^{(1)}(z) \cos l\phi + \rho_{lm}^{(2)}(z) \sin l\phi) J_l\left(j_{lm}\frac{R}{a}\right)$$

where $J_l(R)$ is a Bessel function of order l, j_{lm}, $m = 1, \cdots \infty$, are the positive roots of $J_l(R) = 0$, arranged in increasing order of magnitude, and a is the radius of the cylinder. For the source function, similarly,

$$q(R,\phi,z) = \sum_{\substack{l=0 \\ m=1}}^{\infty} (q_{lm}^{(1)}(z) \cos l\phi + q_{lm}^{(2)}(z) \sin l\phi) J_l\left(j_{lm}\frac{R}{a}\right)$$

where (R,ϕ,z) are the cylindrical coordinates of a point. Then the coefficients satisfy

$$\frac{d^2\rho_{lm}^{(i)}}{dz^2} - \left(\frac{1}{L^2} + \frac{j_{lm}^2}{a^2}\right)\rho_{lm}^{(i)} = -\frac{\tau}{L^2} q_{lm}^{(i)} \qquad (i = 1, 2) \qquad (9.1)$$

Each coefficient therefore is the distribution for an infinite medium with plane sources, with an "effective diffusion length" given by

$$\frac{1}{L_{\text{eff}}^2} = \frac{1}{L^2} + \frac{j_{lm}^2}{a^2}$$

The solutions may therefore be obtained from Section 1 (see Part I, published last month).

If there are no sources, and the density $\rho_0(R,\phi)$ is given over the end $z = 0$ of the cylinder, the other end being $z = a_3$, the solution is given by

$$\rho_{lm}^{(i)}(z) = \rho_{0lm}^{(i)} \frac{\sinh\left(\frac{(a_3 - z)\sqrt{1 + j_{lm}^2 \frac{L^2}{a^2}}}{L}\right)}{\sinh\left(\frac{a_3}{L}\sqrt{1 + j_{lm}^2 \frac{L^2}{a^2}}\right)}$$

2. Fast Neutrons

If the density X and the source function s are expanded in series of the form

$$X = \sum_{\substack{l=0 \\ m,n=1}}^{\infty} [X_{lmn}^{(1)}(\theta) \cos l\phi + X_{lmn}^{(2)}(\theta) \sin l\phi] J_l\left(j_{lm}\frac{R}{a}\right) \sin \frac{n\pi z}{a_3}$$

we will have

$$\frac{\partial X_{lmn}^{(i)}}{\partial \theta} = -\left(\frac{j_{lm}^2}{a^2} + \frac{n^2\pi^2}{a_3^2}\right) X_{lmn}^{(i)} \qquad (i = 1,2)$$

for which the solution, for an arbitrary source function, is

$$X_{lmn}^{(i)}(\theta) = s_{lmn}^{(i)} e^{-\left(\frac{j_{lm}^2}{a^2} + \frac{n^2\pi^2}{a_3^2}\right)\theta} \qquad (9.2)$$

If the source function is $s(R,\phi,z)$, $s_{lmn}^{(1,2)}$ will be given by

$$s_{lmn}^{(i)} = \frac{1}{\pi}\int_0^{2\pi} \begin{pmatrix}\cos l\phi \\ \sin l\phi\end{pmatrix} \cdot \frac{2}{a_3}\int_0^{a_3} \sin\frac{n\pi z}{a_3} \cdot \left[-\frac{2}{a^2 J_{l-1}(j_{lm}a) J_{l+1}(j_{lm}a)}\right] \int_0^a J_l\left(j_{lm}\frac{R}{a}\right) s(R,\phi,z) R dR dz d\phi$$

3. General Problem

In the same notation as above, the thermal neutron density due to an arbitrary fast neutron source is

$$\rho_{lmn}^{(i)} = \frac{\tau s_{lmn}^{(i)} e^{-\left(\frac{j_{lm}^2}{a^2} + \frac{n^2\pi^2}{a^2}\right)\theta_0}}{\left(\frac{j_{lm}^2}{a^2} + \frac{n^2\pi^2}{a_3^2}\right) L^2 + 1} \qquad (9.3)$$

4. Multiplication

Using the same sort of expansion as in the previous sections, we get

$$\rho_{lmn}^{(i)} = \frac{\tau s_{lmn}^{(i)}}{\left[\left(\frac{j_{lm}^2}{a^2} + \frac{n^2\pi^2}{a_3^2}\right) L^2 + 1\right] e^{\left(\frac{j_{lm}^2}{a^2} + \frac{n^2\pi^2}{a_3^2}\right)\theta_0} - k} \qquad (9.4)$$

Critical conditions are given by

$$k = \left[\left(\frac{j_{01}^2}{a^2} + \frac{\pi^2}{a_3^2}\right) L^2 + 1\right] e^{\left(\frac{j_{01}^2}{a^2} + \frac{\pi^2}{a_3^2}\right)\theta_0}; \qquad (j_{01} = 2.405)$$

The solution for the critical dimensions in terms of k is

$$\frac{1}{\sqrt{\frac{j_{01}^2}{a^2} + \frac{\pi^2}{a_3^2}}} = \frac{\pi L_0}{\sqrt{k-1}}\{1 + \eta(\gamma, k-1)\}$$

where η is as defined in earlier sections. The neutron distribution in critical conditions is

$$\rho_{crit} = \rho^{(1)}{}_{011} J_0\left(j_{01}\frac{R}{a}\right)\sin\frac{\pi z}{a_3}$$

$$X_{crit} = X^{(1)}{}_{01}\, e^{-\left(\frac{j^2_{01}}{a^2}+\frac{\pi^2}{a_3^2}\right)\theta} J_0\left(j_{01}\frac{R}{a}\right)\sin\frac{\pi z}{a_3}.$$

NOTE: The symbols used in solving all the problems presented in this paper are contained in the index below.

INDEX OF NOTATIONS

a	Dimensions of a system	L_s	Slowing-down length
a_{crit}	Critical dimension of a system	L_0	Migration length
a_1	Radius of cavity in finite or infinite medium	q	Source of thermal neutrons
a_1, a_2	Cross-sectional dimensions of infinite pile	q_0 or q_{0lm}	Strength of a Fourier component of a plane source of thermal neutrons
a_1, a_2, a_3	Dimensions of finite pile	r	Radius vector
A	Total number of thermal neutrons in a system	r'	Radius of a shell source
b	Mean cosine of the angle of scattering	s_{lmn}	Coefficient in three-dimensional Fourier expansion of s
D	Diffusion constant	s_0	Strength of a plane source of fast neutrons
j	Magnitude of the neutron current	S	Strength of a source of fast neutrons
k	Multiplication factor	t	Time
k_{crit}	Critical multiplication factor	v	Neutron velocity
l	Total mean free path	x, y, z	Cartesian coordinates of a point
l_c	Capture mean free path	$\bar{x}, \bar{y}, \bar{z}$	Coordinates of a point referred to an origin at the center of a pile
l_s	Scattering mean free path		
l_t	Transport mean free path		
L	Diffusion length	x', y', z'	Coordinates of a source

α_n	Roots of the transcendental equation $1 + (\beta^2 - \alpha^2)L^2 = k\, e^{-(\beta^2-\alpha^2)\theta_0}$
β_{lm} or β	$\pi\sqrt{\frac{l^2}{a_1^2}+\frac{m^2}{a_2^2}}$; l, m integers, a_1, a_2 cross-sectional dimensions of a pile
γ	Ratio of slowing down to diffusion length
$\eta(\gamma, k-1)$	A power series in $(k-1)$ whose coefficients are functions of γ (see section 4.4 in Part I)
θ	Symbolic age = square of the slowing-down length
θ_0	θ for thermal neutrons
λ	Constant equal to $k\gamma^2 e^{\gamma^2}$
ρ	Density of thermal neutrons
ρ_{lmn}	Coefficient in three-dimensional Fourier expansion of ρ
τ	Mean lifetime of thermal neutrons against capture
$X(r,t) = X(r,\theta)$	Number of neutrons passing the age mark t per unit time; density of neutrons per unit age interval
X_{lmn}	Coefficient in three-dimensional Fourier expansion of X
$\sim$	Designates a Fourier component in a two-dimensional Fourier expansion

Atomic Energy Commission Publications

THE FOLLOWING AEC DOCUMENTS have been added to the list of publications which the AEC has made available for sale to the public through its Document Sales Agency. This tabulation was compiled from Document Sales Agency List No. 9 and supplements NUCLEONICS' previous listings of these documents. At the prices indicated, these publications can be obtained by sending a money order or check made payable to the Treasurer of the United States to the **Document Sales Agency, P. O. Box 62, Oak Ridge, Tennessee.**

*MDDC or AECD**		*Price*
Biology and Medicine		
1319	The Effects of Total Body X-Irradiation on the Peripheral Blood and Blood Forming Tissues of the Rat (*42 pp*)	$.20
1534	Studies on the Metabolism of Radioactive Nicotinic Acid (*4 pp*)	.05
1538	Negative Effect of Folic Acid on Irradiation Leukopenia in the Cat (*9 pp*)	.10
1550	Induction of Mutations in Paramecium Aurelia by Beta Radiation (*10 pp*)	.10
1555	Determination of Plutonium in Human Urine (*4 pp*)	.05
1570	Relation of Adrenal Cortical Hormone to Lymphoid Tissue and Lymphocytes (*49 pp*)	.25
1576	Relative Effectiveness of Different Intensities of Gamma Radiation in Retarding Mitosis in the Grasshopper Neuroblast (*4 pp*)	.05
1587	Excretion of Radium from the Mouse (*15 pp*)	.10
1596	The Comparative Metabolism and Distribution of Carrier-Free Radio-Arsenic (As^{74})(*19 pp*)	.10
1597	Progress Report for August, 1947—Medical and Health Physics Section. Part A—Cobalt Distribution (*4 pp*)	.05
1615	Technique for Irradiating Microorganisms with Artificially Radioactive Materials. Part II—External Radiation Sources (*12 pp*)	.10
1672	Ionizing Irradiation Disease and a Study of the Protective Nature of Flavonones (*40 pp*)	.20
1680	Utilization of Nicotinic Acid and Its Amide by the Human Erythrocyte in Vitro (*5 pp*)	.05
1763	The Cultivation of the Hematopoietic Tissues by Tissue Culture Methods (*24 pp*)	$.15
1805	The Metabolism of Curium in the Rat (*10 pp*)	.10
1808	A Preliminary Report of the Effect of X-Rays on the Mitotic Activity of Skin (*2 pp*)	.05
1857	Determination of Beryllium in Mouse Tissues (*7 pp*)	.10
2278	Photographic Neutron Dosimetry to Date (*4 pp*)	.05
2280	An Outline of a Beryllium Program (*15 pp*)	.10
Chemistry		
392	Ionic Equilibria and Reaction Kinetics of Plutonium in Hydrochloric Acid Solutions (*38 pp*)	.20
789	Mass Spectroscope for Rapid Analysis in Low Mass Range (*2 pp*)	.05
934	The Nature and Production of Radioactivity (*35 pp*)	.15
973	Component Analysis of Small Uranium Samples (*26 pp*)	.15
975	The Beta-Ray Spectrum of C^{14} (*2 pp*)	.05
1037	Properties of Crystals in Neutron Diffraction Experiments (*13 pp*)	.10
1046	Energy and Half-life of $Beryllium^{10}$ Radioactivity (*5 pp*)	.05
1053	Artificial Radioactive Isotopes of Bismuth and Lead (*17 pp*)	.10
1214	Ca^{45}: Production from Scandium in the Pile, Radiation Characteristics, and Preparation in Carrier-Free Form (*12 pp*)	.10
1405	I. Some New β-Diketones Containing the Trifluoromethyl Group. II. Keto-Enol Relationships in β-Diketones Containing the Trifluoro-Methyl Group (*26 pp*)	.15
1417	The Halides of Neptunium (*16 pp*)	.10
1425	Absolute Cross Section for the Reaction $C^{12}(p,pn)C^{11}$ at High Energy (*3 pp*)	.05

* Documents with numbers 1 through 1779 carry the prefix *MDDC* (Manhattan District Declassification Code); for those numbered 1780 and above, the prefix of *AECD* (Atomic Energy Commission Document) applies.

MDDC or AECD		Price
1447	The Use of Ion-Exchangers to Effect Separation, Concentration and Purification of Small Amounts of Ions, With Particular Reference to the Fission Products (*23 pp*)	$.15
1473	The Ionic Absorption Spectra of the Uranium Halides in a Polar, Non-aqueous Solvent (*13 pp*)	.10
1476	Photoelectrons for Space-Charge Neutralization (*25 pp*)	.15
1508	Investigations on the Absorption Spectra Induced in Single Crystals of Magnesium Oxide by Exposure to Various Types of Radiation (*16 pp*)	.10
1535	Techniques for Irradiating Microorganisms with Artificially Radioactive Materials. Part I—Radioactive Material in Suspension (*12 pp*)	.10
1541	Analysis of Small Amounts of Chromium in UF_6 (*7 pp*)	.10
1542	Determination of Oxygen in Tank Nitrogen by Its Conversion to Water and the Measurement of the Dew-point Temperature (*7 pp*)	.10
1548	Further Measurements of Polarized Neutrons (*4 pp*)	.05
1551	Determination of HF in Gas Mixtures by the Differential Flow Analyzer (*20 pp*)	.10
1556	A Mass Spectrograph for Radioactive Isotopes (*12 pp*)	.10
1558	Diffraction Effects in Neutron Attenuation Measurements (*4 pp*)	.05
1559	X-Ray Structural Studies of the Tetrachlorides of Uranium and Thorium (*4 pp*)	.05
1561	Some Procedures for the Preparation of Highly Purified Adenosine Triphosphate (*3 pp*)	.05
1566	Short-Lived Halogen Fission Products (*34 pp*)	.20
1580	Proton Angular Distribution For 90 Mev Neutron Proton Scattering (*4 pp*)	.05
1585	Uranium Hydride—I. Preparation, Composition, and Physical Properties (*12 pp*)	.10
1586	Uranium Hydride—III. Dispersions in Mercury (*5 pp*)	.05
1588	The Intermediate Uranium Fluoride Compounds (α-UF_5, β-UF_5, U_2F_9 and U_4F_{17}) (*8 pp*)	.10
1589	Phosphorus Turnover and Photosynthesis (*13 pp*)	.10
1590	The Assessment of Gamma Radiation Dosage By Means of Radioisotopes in Mock-Ups (*2 pp*)	.05
1605	Preparation of Thin U_3O_8 Films (*13 pp*)	.10

MDDC or AECD		Price
1610	The Bromine Displacement Method for the Determination of Fluorine in Gas Mixtures (*11 pp*)	$.10
1627	Considerations on the Existence of Element 61 in Nature (*3 pp*)	.05
1632	Fission Yields in Uranium-233 (*11 pp*)	.10
1665	A Study of the Reaction Between Beryllium and Aurin Tricarboxylic Acid (*13 pp*)	.10
1666	Fluorescence Studies of Plutonium, Neptunium, and Americium (*15 pp*)	.10
1676	Stars in Photographic Emulsions Initiated By Deuterons Part I. Experimental (*14 pp*)	.10
1683	A New Photographic Material for Gamma-Ray Dosimetry (*13 pp*)	.10
1687	The Isotopic Constitution of Europium Gadolinium and Terbium (*17 pp*)	.10
1703	The Potential of the U(V), U(VI), Couple and Kinetics of U(V) Disproportionation in Perchlorate Media (*19 pp*)	.10
1708	Electrolytic and Polarographic Determination of Zinc in Thorium (*13 pp*)	.10
1710	The Higher Chlorides of Uranium (*3 pp*)	.05
1714	Determination of *p*-Toluenesulfonamide (*2 pp*)	.05
1729	Vapor Phase Chlorination of Uranium Oxides (*4 pp*)	.05
1733	Fluorescence of Uranium Trioxide Hydrates (*8 pp*)	.10
1739	The Relation of Backscattering to Self-Absorption (*4 pp*)	.05
1740	The Isotopic Constitution of Praseodymium and Neodymium (*2 pp*)	.05
1758	Hemin Synthesis with Glycine Containing C^{14} in its Alpha-Carbon Atom (*3 pp*)	.05
1765	Comparison of Methods of Obtaining Surface Area of Crystalline Solids From Vapor Adsorption Isotherms (*13 pp*)	.10
1777	The Quantitative Spectrographic Analysis of the Rare Earth Elements (*8 pp*)	.10
1784	Properties of 86s $I^{(130)}$ (*8 pp*)	.10
1798	The Crystal Structure of Na_2UF_7 (*3 pp*)	.05
1810	Ion-Exchange Separation of the Alkali Metals (*2 pp*)	.05
1816	A Rapid, Precise Microbalance Technique (*8 pp*)	.10
1819	The Determination of Palladium and Nickel with Alpha-Furildioxine (*8 pp*)	.10
1831	Loss of Radioactivity From Barium Carbonate Samples (*4 pp*)	.05

MDDC or AECD		Price
1832	Degradation of Isotopic Lactate and Acetate (*5 pp*)	$.05
1848	The Effect of Liquid Fluorine on Some Protective Gloves (*8 pp*)	.10
1858	Remodeling a Laboratory For Radiochemical Instruction or Research (*6 pp*)	.10
1863	Thermodynamic Functions for Tritium and Tritium Hydride. The Equilibrium of Tritium and Hydrogen with Tritium Hydride. The Dissociation of Tritium and Tritium Hydride (*9 pp*)	.10
1864	The Hydrolytic Behavior of Uranium and the Transuranic Elements (*12 pp*)	.10
1873	Short Lived Halogen Fission Products (*10 pp*)	.10
1874	Ranges in Air and Mass Identification of Plutonium Fission Fragments (*11 pp*)	.10
1875	Opacity of Solar Material (*7 pp*)	.10
1878	The Thermodynamics of Intermediate Uranium Fluorides from Measurements of the Disproportionation Pressures (*14 pp*)	.10
1880	Radiations of UY (*7 pp*)	.10
1974	On the Isotopic Composition of Meteoritic and Terrestrial Gallium (*2 pp*)	.05
1994	Production of New Tc Activities from Separated Mo Isotopes (*6 pp*)	.10
2041	Excitation Time of Silver-Activated Zinc Sulphide on Electron Bombardment (*1 p*)	.05
2081	The Formation of U^{232} by Helium Ions on Thorium (*3 pp*)	.05
2093	New Crystal Structure Results—I (*9 pp*)	.10
2121	The Beta Spectrum of $Hg^{(203/205)}$ (*3 pp*)	.05
2134	Some Observations on the Basic Chemistry of Plutonium (*4 pp*)	.05
2166	Artificial Collateral Chains to the Thorium and Actinium Families (*3 pp*)	.05
2218	Neutron Deficient Isotopes of Cerium and Lanthanum (*3 pp*)	.05
2236	Approach to Equilibrium by a Thermal Diffusion Column—I. Column Closed at Both Ends (*6 pp*)	.10
2318	Determination of Hydrogen in Fluorocarbons (*4 pp*)	.05
2320	Chambers Works Process for the Manufacture of Fluorine Cell Electrolyte (KF·2·3 HF) at East Area (*4 pp*)	.05
2330	Chambers Works Process for the Recovery of Fluorine Cell Electrolyte (KF·2·3 HF) at East Area (*4 pp*)	.05

MDDC or AECD		Price
Instruments		
282	Investigation of Proportional Counters (*22 pp*)	$.15
1010	Construction Features of a Circuit for Coincidence Measurements and Applications of the Circuit to Nuclear Problems (*10 pp*)	.10
1157	Portable Alpha Survey Meter, Mark I, Model 41A (*3 pp*)	.05
1664	The Clinton Pile Oscillator (*13 pp*)	.10
1670	Mass Spectrometer for Leak Detection (*10 pp*)	.10
1697	Design Study for a 10-Bev Magnetic Accelerator (*17 pp*)	.10
1849	Functional Description of the 184-Inch Cyclotron Pulsed Arc System and Maintenance Instructions (*14 pp*)	.10
1856	A Pressure Ionization Chamber for the Measurement of Neutron Fluxes at Tolerance Level in Portable Instruments (*12 pp*)	.10
2038	Plan of 12 Mev Electrostatic Accelerator under Construction at Los Alamos (*9 pp*)	.10
2145	High-Voltage, Pulse-Type, Radio-Frequency Power Supply (*7 pp*)	.10
2271	Exposure Meter for Photomicrography (*5 pp*)	.05
Metallurgy and Ceramics		
1673	Production of Rarer Metals (*11 pp*)	.10
1949	The Production of Thin Be Foils (*4 pp*)	.05
Physics		
1014	Course in Nuclear Physics for Engineers (*151 pp*)	.50
1398	Further Evidence for a γ-p Process in Be^9 (*6 pp*)	.10
1399	Total Cross Sections of Nuclei for 90-Mev Neutrons (*4 pp*)	.05
1458	Excitation Function of the Reaction $C^{12}(p,pn)C^{11}$ at High Energies (*5 pp*)	.05
1490	The Neutron Spectrum of Boron Bombarded by Polonium-Alphas (*7 pp*)	.10
1514	Calculation of Internal Conversion Coefficients (*14 pp*)	.10
1633	Technique for Observing Nuclear Disintegrations and Scattering in Small Gas Volumes (*10 pp*)	.10
1641	An Ion "Velocitron" (*6 pp*)	.10
1679	Fission Excitation Functions (*6 pp*)	.10
1682	The Effect of Crystal Orientation on the Scattering of Slow Neutrons	.05

MDDC or AECD		Price
1685	Cross Section and Crystal Orientation in Extruded Graphite (and Aluminum) (*3 pp*)	$.05
1695	High Frequency Vacuum Breakdown Tests for Copper and Copper-Plated Ceramic Surfaces (*4 pp*)	.05
1747	The Thermal Conductivity of Uranium Hexafluoride (*23 pp*)	.15
1825	Angular Distribution of *n-p* Scattering with 90-Mev Neutrons (*3 pp*)	.05
1827	Electronic Classifying, Cataloging, and Counting Systems (*15 pp*)	.10
1883	Yield of Photoneutrons from U^{238} Fission Products in Be (*13 pp*)	.10
1846	Production of Mesons by the 184-Inch Berkeley Cyclotron (*4 pp*)	.05
1855	Self-Delayed Coincidences With Scintillation Counters (*1 p*)	.05
1860	The Beta-Spectrum of Os^{193} (*5 pp*)	.05
1867	Behavior of the Philips Ionization Gauge in Air (*21 pp*)	.10
2052	Recording Dosimeters for One Microsecond X-Ray Pulses (*11 pp*)	.10
2126	Stars in Photographic Emulsions Initiated By Alpha Particles (*6 pp*)	.10
2149	Character of the Radiation Field and Shielding at the 184-Inch Cyclotron (*6 pp*)	.05
2196	Upper Limits of the Fission Cross Sections of Bismuth, Lead, Mercury, Gold, Iridium and Tungsten for 14-Mev Neutrons (*6 pp*)	$.10
2200	Physical Considerations Concerning the Design of the Bevatron (*14 pp*)	.10
2232	The Alpha-Particle Energy of Ac^{227} (*2 pp*)	.05
2264	"Cross-Over Transitions" in Cl^{38}, Co^{60}, Br^{82}, and Sb^{124} (*3 pp*)	.05

Nuclear Science Abstracts

Vol. I, No. 10.	Nuclear Science Abstracts (*77 pp*) (November 30, 1948)	.30
Vol. I, No. 11.	Nuclear Science Abstracts (*81 pp*) (December 15, 1948)	.30

Subscription Rates for Nuclear Science Abstracts:

Vol. I.	July 15–December 30, 1948 (12 issues)	3.75
Vol. II.	January 15–June 30, 1949 (12 issues)	3.00

A subscription for either of the Volumes includes the cumulative subject and author index.

Miscellaneous

Vol. I.	Heat Transfer Lectures (NEPA 804-IER-10) (December 1948) (*275 pp*)	.90

AEC DEPOSIT ACCOUNTS

To facilitate the purchase of certain Atomic Energy Commission publications, the Document Sales Agency will accept orders on deposit accounts made out on regular deposit order blanks *in triplicate* as obtained from the Superintendent of Documents, Washington 25, D. C. All order blanks must have the deposit account number assigned by the Superintendent of Documents on all copies before they can be honored by the agency.

However, all orders must be directed to the Document Sales Agency, P. O. Box 62, Oak Ridge, Tennessee, and not to the Superintendent of Documents.

New deposit accounts may be opened with the Superintendent of Documents, Washington 25, D. C., the minimum amount being $5.00. New depositors may restrict their accounts to charges for AEC documents only, or may open a general account for the purchase of any government publications.

NUCLEONIC EVENTS

BACHER OUTLINES AEC NUCLEAR REACTOR PLANS

Plans for four new-type nuclear reactors, which will form the "backbone of the United States' reactor development program at the present time," were outlined by Robert F. Bacher, member, U. S. Atomic Energy Commission, in a talk last month before the American Academy of Arts and Sciences in Boston. Dr. Bacher predicted that within eight to ten years it will be possible to design a large-scale reactor for the development of power, and from this to determine whether nuclear power is economically feasible.

The AEC does not contemplate the construction of any other major units as part of the reactor development program in the next year and a half. However, plans beyond that time may be altered by present studies.

The details of the present reactor program are:

1. A materials testing reactor which, as its name indicates, will be used in the studies of materials to be employed in building reactors. It has been in the process of design at the Oak Ridge National Laboratory for the past two years. Plans for its construction are now being prepared jointly by the Argonne National Laboratory and the Oak Ridge National Laboratory.

2. A Navy reactor designed as a land-based prototype of a reactor for use in propelling naval vessels of appropriate types. The Westinghouse Electric Corporation is expected to start on the construction of this unit in about one year.

3. An experimental "breeder" reactor designed to operate with high-energy neutrons. To be used to explore further the possibilities of breeding and also of power production this fast reactor has been under design at Argonne for the past two years. It differs from the fast reactor now in operation at Los Alamos in that it uses uranium-235 as its fuel instead of plutonium and will operate at a very much higher power level. Another feature is that it will use a liquid metal heat transfer medium.

4. An experimental breeder reactor designed to operate with neutrons of intermediate energy and to explore their possibilities for breeding, as well as to produce usable power. Construction of this reactor, to be built by the General Electric Company at the Knolls Laboratory, is expected to get underway this year.

To test reactors under high-level operating conditions, the AEC will build a field station in the western part of the country in the next few years. This new test station will be essentially a field facility for Argonne. Work at the field station will be devoted to the final development and proving under actual operating conditions of new types of reactors. How many new reactors will be built at this new site in the next few years will depend upon the whole course of reactor development. At present it is definitely planned to build there two of the four reactors now on the drawing boards—the materials testing reactor and the Navy power reactor. Looking to the long-range development of reactors, it is likely that in the future several

additional reactors will be built at this new location, as well. For this reason, many of the same security, safety, and operation requirements that governed the selection of the Hanford site necessarily apply in the selection of the new test site.

The most long-range of these studies is the so-called NEPA project (Nuclear Energy for the Propulsion of Aircraft) to develop a reactor to power an airplane. Under the supervision of the Air Forces and in cooperation with AEC, Fairchild Engine and Airplane Corporation has been studying this problem for the past two and one-half years. The whole subject of aircraft propulsion by nuclear power was recently surveyed by MIT (the Lexington Project Report) and the results of these studies are now being used for planning new work in this field.

Another possible reactor is a so-called homogeneous type in which the nuclear raw material, the moderator, the coolant, and the reflection material are all mixed together and not placed within the pile as separate entities.

AEC ISSUES FIFTH SEMIANNUAL REPORT

The fifth semiannual report of the U. S. Atomic Energy Commission to Congress, issued last month, included descriptions of progress in the production of fissionable material, research in the physical sciences and biology and medicine, and developments in military applications. Scheduled to be issued this month are reports on nuclear reactors for aircraft, and developments in use of nuclear reactors in power plants. To be issued within the next several months are a report on disposal of radioactive wastes, a source book on atomic energy and an atomic weapons handbook.

The following are highlights taken from AEC'S latest report:

Production

Major construction program. To increase capacity for production of fissionable material, as well as efficiency, it is necessary to carry through a major plant construction program extending over a period of five years. At the end of 1947 the AEC had drawn the broad outlines of this program; some designing had been completed, many engineering problems solved, quantities of materials and equipment procured, several contracts let; and preliminary construction was under way.

By the spring of 1948, the building of these new major facilities for production of fissionable materials had become the greatest single construction program in American peacetime history. Work which will eventually cost more than 700 million dollars was under way. It centers at the Hanford, Washington, plutonium works. The construction there now employs close to 15,000 workers.

Breakdown avoided. With better facilities and process, the production system turned out more fissionable materials during 1948 than in 1947. In spite of higher wages and greater costs of materials, the average cost of the product is less per pound today than it was a year ago. The yield of product from each ton of raw material continued to increase because of a reduction of the amount of uranium lost in factory wastes. During 1947 the fissionable materials industry had faced the possibility that breakdown of worn, corroded, and outmoded equipment might interrupt production. At the end of 1948 the additions and repairs made to plants had reduced this danger.

Recovery of scrap. Because of the great value of uranium, production methods are designed to reduce to a minimum losses of the metal, but some loss is inevitable. It has been necessary to develop a system of salvage for various process sludges, fluids, concentrates, dusts, dross, slags and sweepings. Waste is recovered at all steps in the processing chain. In 1948

process improvements in the conversion of waste to feed materials resulted in increased recovery.

Improvement of barriers. The porous barriers through which uranium gas is diffused at Oak Ridge are unlike anything ever before devised by man. They must contain billions of holes per square inch, each one a few ten-millionths of an inch in diameter. They must be very thin and therefore fragile, yet must withstand considerable pressure. They must be supplied in enormous quantities—the total area of barriers used in the plant is measured in square miles.

Barrier manufacture since its inception has been a "batch-type" operation. Recent developments, however, have partially overcome this difficulty and it is now felt that continuous production of barriers may be possible. Production efficiency would be greatly increased by this change.

Development of fluorothene. Uranium hexafluoride, the feed material of the gaseous diffusion process, is a difficult substance to handle, being so reactive it eats through glass. Yet in the gaseous diffusion process it must pass through tens of thousands of pumps, valves and couplings without leakage. No ordinary pump packing or valve seat can contain it. An entirely new substance, a corrosion resistant plastic compound called fluorothene, was developed during the war. Because of the potentialities this plastic offered during 1947 and 1948, the AEC and the contractor have developed new and improved methods of using it at various points in the gaseous diffusion process.

New gaseous diffusion plant. There is now definitely projected a large addition to the present gaseous diffusion plant at Oak Ridge. Construction is expected to start on the $70,000,000 project in the summer of 1949 and the plant should be in operation by late 1951. When this addition is complete, uranium-235 production will be increased considerably and the production of the new plant will be much more economical than the present production.

Hanford program. The serious deterioration of the reactors, resulting from more than three years of intensive operation, required a major overhaul and reconditioning program at Hanford. At the same time the national interest required an increasing supply of fissionable material. The Commission's program at Hanford has shaped itself around three major objectives:

1. Rehabilitating existing equipment and operating it more efficiently to prolong its useful life and raise the rate of output.
2. Building plants to replace existing facilities plus additional plants for greater production capacity.
3. Developing new and more efficient processes and operating techniques.

Physical Sciences

Physics research progress. A major part of the Commission's physical research funds in 1948 was used to support work in physics, particularly nuclear physics, the design and construction of particle accelerators, design of research reactors, design and construction of radiation detection instruments, and the improvement of isotope separation methods by means of the mass spectroscope.

The most extensive field of data accumulation comprises the studies of what happens when the fundamental particles of the atom collide with one another or with the nuclei of varying forms or isotopes of the atoms of the 96 elements so far identified.

Mesons produced. At the Radiation Laboratory of the University of California, the 184-inch cyclotron, used in bombarding a variety of target materials, produced reactions not before observed by nuclear physicists. Of particular interest, scientists at this laboratory reported the first artificial production of mesons.

Magnetic moments studied. During 1947–48 scientists at the Argonne National Laboratory made a series of very precise measurements of the

magnetic properties of tritium (hydrogen-3) and helium-3. Under normal conditions, the total magnetic moment of a system should be equal to the sum of the moments of the individual parts of the system. The Argonne measurements for these atoms were about ten percent higher than the expected values for the sums of the moments for the individual protons and neutrons. This discovery indicates that there must be some additional magnetic forces in the system. Magnetism is associated with a flow of current, and the discovery of the additional magnetic moment suggests that an electric current is flowing around the nucleus. Scientists believe that this so-called exchange current is associated with the meson in the nucleus and that both play important parts in holding the nucleus together. There are many gaps, however, in present knowledge.

Magnetic separation. A vigorous development and research program has been carried on at the electromagnetic separation plant (Y-12) at Oak Ridge which has not been in operation for the production of uranium-235 since shortly after the end of the war. However, the magnetic machines at Y-12 can separate isotopes of almost any element.

Helium 3 and 4 studied. Physical chemists at Los Alamos in 1948 succeeded for the first time in liquefying helium-3, the lightweight stable isotope of helium. Both helium-3 and the heavier stable isotope, helium-4, are of unusual scientific interest because of their remarkable low-temperature properties in the neighborhood of absolute zero. Helium-4 is the only substance that has no normal freezing point. When cooled, instead of freezing to a solid, helium-4 converts to a unique liquid which has a viscosity of zero.

Study heavy elements. Much research in chemistry financed with Commission funds has to do with chemistry of the heavy elements—lead and heavier. More knowledge of the chemistry of these elements is needed in order to solve the problems of production and handling of fissionable materials. Basic chemical properties of certain other elements are also under investigation because of their potential usefulness in power reactors as moderator materials, coolants, or structural materials.

Research in separation processes. At the Ames Laboratory, Ames, Iowa, pilot plants have been set up using certain types of chemical separation processes in which the chemicals to be separated stick to organic resins or transfer from one liquid to another as the liquids flow past each other through a column. Fundamental research on such processes are being intensively studied.

Biology and Medicine

Does radiation stimulate plant growth? Early in 1948, the AEC arranged with the Department of Agriculture and a number of state experiment stations to run a comprehensive series of experiments in the application of low-level radioactive materials to growing crops. The widespread, one-season experiments indicated strongly that the farmer *cannot* expect increased yield from money invested in radioactive materials available at present. A second series of tests will be run in 1949. (These studies are quite separate and distinct from the numerous investigations which are being made in fertilizer tracer research, where radioactive isotopes are being used to gain further understanding about the growth of plants, as well as the rate and volume of movement of various fertilizer materials in the soil, their absorption into plants, and their accumulation in plant parts. Such studies are expected to solve practical problems of fertilizer applications which are of direct dollars-and-cents interest to farmers.)

Genetic studies. A major portion of the AEC biology research program is devoted to studies of the effects of the various radiations on living cells, with special emphasis on their effects on chromosomes and the genetical make-up or inheritance. The AEC has undertaken studies which range from effects

of radiation on individual cells to genetic results expressed in terms of population numbers and mutation types. Test organisms now being studied include high plants, animals, molds and bacteria.

New Mexico survey. Data collected by the University of California at Los Angeles under an AEC contract have established the fact that there are no appreciable hazards of external radiation for men or livestock at the New Mexico "Trinity" bomb test site outside of the fenced area of several hundred acres.

Bikini survey. In July, an expedition sponsored by the AEC, with the assistance of the Navy, completed a survey of the effects of the atomic explosion on marine plant and animal life at Bikini and Eniwetok Atolls in the Pacific. The survey was carried out by the Schools of Applied Fisheries, University of Washington, under AEC contract. It is too early to present any conclusive data on the after-effects of atomic explosions on plant and animal life. Further studies are planned for the future.

Beryllium. It is well recognized that the element beryllium, which may be used as a moderator to slow down neutrons in nuclear reactions, may cause acute and chronic lung disease of a serious nature, and cases have developed in employees of several concerns from whom the AEC purchases beryllium. Accordingly, in 1948, the AEC initiated extensive studies regarding permissible concentration of beryllium, prevention of injury, diagnosis, and treatment. As a result of these studies, reliable authorities now predict that over 90% of the hazard can be removed.

Plutonium. The element plutonium may cause serious damage to the liver, kidney, and bone marrow if enough of it gets into the blood stream. Scientists at Los Alamos have developed an accurate test to detect and measure plutonium excreted from the body and thus to keep a clinical watch over personnel whose work puts them in danger of overexposure. Argonne Laboratory has developed another attack upon this problem by demonstrating that the relatively harmless element zirconium will displace large amounts of plutonium in the body and thus eliminate it.

Surveys. The AEC has surveys underway at all major installations to determine precisely the steps that need to be taken to safeguard the surrounding areas—to determine to what extent conventional waste disposal plants and water treatment plants are effective in removing radioactive materials. At Oak Ridge, the TVA, the U. S. Weather Bureau, the U. S. Public Health Service and the Geology Department of the University of Tennessee undertook such a survey of the surrounding areas in 1948. At Los Alamos the Public Health Service and the University of California are participating. At Brookhaven, the Weather Bureau and the U. S. Geological Survey are assisting. Similar activity is going on at other laboratories.

Radioactive cobalt. The AEC has studies underway on cobalt-60, which shows promise of being a cheap substitute for radium. Numerous basic problems, however, must be solved before this is usable for clinical application. For example, work must be done so that the methods now used in radium therapy can be utilized with cobalt. As soon as these problems are solved it is reasonable to expect that cobalt-60 will be available for therapeutic purposes to a much larger number of medical centers than are now in a position to afford radium.

184" CYCLOTRON CONVERTED TO PRODUCE PROTONS

Official announcement of the redesign of the 184-inch cyclotron at the University of California to permit acceler-

ation of protons was made by Kenneth MacKenzie at a meeting of the American Physical Society at Berkeley last month. Whereas previously the machine could only produce 200-Mev deuterons and 400-Mev alpha particles, it can now also produce 350-Mev protons. The conversion was made possible by a change in the oscillator circuit, necessary to compensate for the smaller mass of the proton as compared with the deuteron.

Also announced at the same meeting, by E. M. McMillan, was successful operation of the university's 300-Mev synchrotron.

N. Y. TEACHERS STUDY ATOMIC ENERGY

A fourteen-lesson course in the scientific, political and military aspects of atomic energy was started last month for New York City public school teachers, according to an announcement by Mayor William O'Dwyer. Sponsored by the New York Board of Education and the Atomic Energy Commission, the course will have the following as some of its lecturers:

Senator Brien McMahon, of Connecticut, chairman of the Congressional Atomic Energy Committee; Frederick Osborn, U. S. deputy to the U. N. AEC; J. R. Dunning, Columbia University; Lyle C. Borst, Brookhaven National Laboratory; W. E. Kelley, manager of the AEC's New York office; Brig. Gen. James McCormack, Jr., military officer in charge of applications of weapons; Paul Aebersold, chief, Isotopes Division, Oak Ridge; and Sumner Pike, member of the AEC.

RADIOISOTOPES USED IN PISTON RING STUDIES

Experiments with piston rings irradiated in the Oak Ridge nuclear reactor have been described in an announcement by the California Research Corporation, a subsidiary of Standard Oil of California, and the Atomic Energy Commission. The corporation is said to be successfully using radioactive piston rings to test the effect of fuels and lubricants on engine wear.

Also described were two other experiments with radioisotopes, one to develop a method to permit location of a sample of oil in a pipeline from outside the pipe, the other to study methods of producing better petroleum fuels.

NUCLEAR NEWSMAKERS

The Westinghouse Electric Corporation has announced three appointments in its atomic power division. **Philip N. Ross** has been named assistant director of research, **E. L. Kuno,** assistant to the division manager, and **L. C. Mechling, Jr.,** works engineer.

Lauriston S. Taylor has been appointed assistant chief of the atomic and molecular physics division of the National Bureau of Standards. Since he joined the NBS staff in 1927, Dr. Taylor has headed the X-ray development program and will remain in his present capacity as chief of the X-ray section. His research includes X-ray dosage measurement and standardization, evaluation of radiation hazards and protective measures, ionization of liquids, high-voltage generators and accelerators, and problems in nuclear physics.

P. M. S. Blackett, British physicist who was recently awarded the Nobel Prize for physics, will receive the Dalton Medal from the Manchester Literary and Philosophical Society. Awarded only six times previously, the medal commemorates John Dalton, discoverer of the atomic theory. The society, which has been in existence for 167 years, will make the presentation in October.

ABSTRACTS

CHEMICAL PUBLICATIONS

Szilard-Chalmers reaction on antimony, L. Melander (Nobel Inst. for Physics, Stockholm, Sweden), *Acta Chem. Scand.* **2,** 290–291 (1948). Szilard-Chalmers experiments were carried out with phenylstibinic acid and triphenylstibine in order to obtain concentrated isotopes. Attempts to separate the activity in irradiated phenylstibinic acid by hydrogen sulfide precipitation and by zinc reduction were unsuccessful; a slight concentration was effected by dissolving the irradiated acid in chloroform, extracting the solution with an aqueous solution of antimony chloride and tartaric acid, and then precipitating the antimony as the sulfide. This latter procedure (modified slightly) was used to extract 50%–60% of the activity in irradiated triphenylstibine.

On the determination of radioactive hydrogen, L. Melander (Nobel Inst. for Physics, Stockholm, Sweden), *Acta Chem. Scand.* **2,** 440–446 (1948). A complete description is given for the analysis of tritium, using rather simple apparatus. The tritium sample is reduced to hydrogen with magnesium turnings, and the hydrogen is introduced together with methane, into a Geiger-Müller tube. Methane was found to be a good quenching gas for use with hydrogen in a counter tube connected to a Neher-Pickering quenching circuit. The measured activity was found to be proportional to the amount of tritium present in the counter tube, regardless of the total hydrogen pressure and the absolute amount of tritium over a considerable range. Tritium may be determined in water with an accuracy of $\pm 2\%$.

Sensitivity and exposure graphs for radium radiography, H. E. Johns, C. Garrett (Univ. of Saskatchewan, Saskatoon, Canada), *Can. J. Research* **26A,** 292–305 (1948). The radiography of steel by use of gamma rays is discussed. A slotted wedge steel penetrameter was used to obtain sensitivity curves for several types of X-ray film. These sensitivity curves are important for routine gamma-ray testing.

The γ-rays of thorium CC′, S. C. Fultz, G. N. Harding (Natl. Research Council of Canada, Chalk River Lab., Chalk River, Ontario), *Can. J. Research* **26A,** 313–325 (1948). The total γ-ray energy of ThCC′ was obtained by measuring coincidences between the γ-rays of ThCC′ and the subsequently emitted α-particles of ThC′; this value is 0.14 ± 0.014 Mev per disintegration of ThCC′. The level scheme having γ-rays of energies 0.726 and 1.80 Mev (the former being taken as electric quadrupole) is favored. Precautions were taken to minimize the contribution to the coincidence rate of the bremsstrahlung excited by the β-rays of ThCC′ in the source holder.

A 600 kv ion accelerator, J. V. Jelley, E. B. Paul (Natl. Research Lab., Ottawa, Canada), *Can. J. Research* **26F,** 419–425 (1948). A 600-kv X-ray set was modified so that it could be used to accelerate positive ions. Details of ion source, power column, and control gear are given. The accelerator provides a strong source of neutrons from (d,n) reactions, and of γ-rays from (p,γ) reactions. With the ion source running on hydrogen, the total current on the target was from 250 to 300 μa. About 80% of the ion beam was found to be atomic. The neutron yields from various targets using 600 kv deuterons were: $D_2O + P_2O_5$ target, 250 mc equivalent per μa; Be target, 600 mc equivalent per μa; Li target, 500 mc equivalent per μa.

The first isolation of element 93 in pure compounds and a determination of the half-life of $_{93}Np^{237}$, L. B. Magnusson, T. J. LaChapelle (Univ. of Chicago, Ill.), *J. Am. Chem. Soc.* **70,** 3534–3538 (1948). By the use of neutron-irradiated uranium sources, microgram quantities of $_{93}Np^{237}$ compounds were isolated for the first time in pure form. Np (IV) dioxide and sodium neptunium (VI) dioxytriacetate were prepared and identified by X-ray analysis, thus establishing 4+ and 6+ oxidation states. The specific α-activity of Np^{237}, as neptunium dioxide, was calculated to be 1520 disintegrations per minute-microgram, which corresponds to a half-life of 2.20×10^6 years. These values are believed to be accurate to within 5%.

The preparation of solid neptunium compounds, S. Fried, N. Davidson (Argonne Natl. Lab., Chicago, Ill.), *J. Am. Chem. Soc.* **70,** 3539–3547 (1948). A study was made of the preparation and properties of

several of the simpler solid neptunium compounds. A detailed description of the micro-techniques used in the preparation is given. Neptunium trifluoride, tetrafluoride, and hexafluoride were prepared by hydrofluorination of the dioxide, oxyfluorination of the trifluoride, and fluorination of the trifluoride, respectively. Neptunium tetrachloride was prepared by the action of carbon tetrachloride vapor on Np (IV) oxalate or neptunium dioxide at 500°; the reduction of the tetrachloride by hydrogen at 450° gave the trichloride. No higher chlorides could be prepared by the action of chlorine on neptunium tetrachloride.

The action of aluminum bromide on neptunium dioxide gave the tetrabromide, while the tribromide was obtained by the same reaction when excess aluminum was present. Neptunium triiodide was prepared by the action of aluminum iodide on neptunium dioxide, and neptunium metal by the reaction of barium vapor and neptunium trifluoride at 1200°. A hydride was obtained by the action of hydrogen on neptunium metal. The reaction at 1000° of neptunium dioxide with a hydrogen sulfide-carbon disulfide mixture gave the oxysulfide, while further treatment produced the sesquisulfide. A higher oxide of neptunium could not be made by the ignition of Np (IV) nitrate with high pressure oxygen at 400°. The stabilities of uranium, neptunium, and plutonium compounds in various oxidation states are discussed.

The quantitative determination of C^{14} activity in biological systems by direct plating, J. R. Hogness, L. J. Roth, E. Leifer, W. H. Langham (Los Alamos Scientific Lab., N. Mex.), *J. Am. Chem. Soc.* **70,** 3840–3842 (1948). A method is described of direct plating of aliquots of biological fluids onto counting disks, and subsequently determining the radioactivity with a thin mica window Geiger-Müller counter. The fluid to be plated is delivered quantitatively from a micropipet and spread onto a rotating disk; an infrared lamp and a hot air drier suspended over the rotating disk provide rapid drying. Calibration curves must be made for different biological fluids and for each radioactive isotope used as a tracer. The method is applicable only to solids with low vapor pressures at 100°. The amount of back-scattering increases with increasing atomic number of the background plate.

Radioactive diisopropyl fluorophosphate, B. Witten, J. I. Miller (Army Chemical Center, Maryland), *J. Am. Chem. Soc.* **70,** 3886–3887 (1948). Diisopropyl fluorophosphate-P^{32} was synthesized on a millimole scale from potassium dihydrogen phosphate-P^{32} in 33% yield. The specific activity of the product was 20 mc/g.

Delayed neutrons, S. Das (Inst. of Nuclear Physics, Calcutta, India), *Nature* **162,** 853 (1948). The (e,n) reaction may result in the delayed emission of neutrons. The ejection of neutrons from Kr^{87} and Xe^{137} through electrodisintegration by high-energy electrons is therefore inferred. It is suggested that the delayed neutron emitter detected after bombardment of oxygen by 195-Mev deuterons is not O^{17} (as had been previously proposed), but N^{16}. The latter emits β-rays of approximately 6.2 Mev, and these high-energy electrons cause simultaneous electrodisintegration of the remaining nuclei of N^{16} to form N^{15}, with the emission of delayed neutrons.

Reduction of dead times in Geiger-Müller counters, B. Collinge (Univ. of Liverpool, Eng.), *Nature* **162,** 853–854 (1948). Experiments carried out showed that reduction in the dead time of Geiger-Müller counters may be achieved by localization of the ion sheath, which is thus prevented from spreading along the whole length of the wire, leaving part of the counter sensitive to further ionizing events. By the use of a circuit which reduces the wire potential to 20–30 volts of that of the cathode for about 1 microsecond after each count, dead times of only 3–4 microseconds were obtained. Such a circuit is less likely to induce spurious counts than is a circuit which reverses the wire voltage.

A traveling-wave linear accelerator for 4-Mev electrons, D. Fry, R. B. R.-Shersby-Harvie, L. B. Mullett, W. Walkinshaw (Atomic Energy Research Estab., Harwell, Eng.), *Nature* **162,** 859–861 (1948). A new accelerator is described, similar in principle to a 0.5-Mev model already built and described. The length of the accelerator is 2.0 meters and the r-f power is 2.0 megawatts. The pulse of 4-Mev electrons observed through a spectrometer was extremely narrow for low r-f powers and was confined to the beginning of the 2 μsec r-f pulse. The

measured phase error for the 2-meter length of corrugated wave guide was only 18° in 22 wavelengths, while the over-all loss was 2.5 db. The accelerator functions satisfactorily over a range of about 3 Mc/sec, and operates best at 2998 Mc/sec. The efficiency in terms of r-f power input is 30%. The width of the spectrum is generally unaffected by increased beam current, but the energy of the peak falls by about 250 kev.

Latitude effect of penetrating cosmic ray showers, V. Appapillai, A. W. Mailvaganam (Univ. of Ceylon, Colombo), *Nature* **162,** 887–888 (1948). It has been suggested by Jánossy that local penetrating showers are produced mainly by nucleons that are latitude-sensitive. The transition effect of local penetrating showers should therefore show a marked latitude effect. However, experiments carried out in Colombo, and compared with results obtained at Manchester, showed no observable latitude effect of penetrating showers.

Origin of cosmic rays, J. W. Dungey, F. Hoyle (Magdalene College, Cambridge, Eng.), *Nature* **162,** 888 (1948). Even if the interstellar magnetic field is as high as 10^{-10} gauss, the application of the conservation of momentum to an assembly of particles moving in an electromagnetic field shows that the observed isotropy of cosmic rays incident on the earth is not a consequence of an interstellar magnetic field. The main source of cosmic rays must therefore be external to our galaxy.

A proposed new form of dielectric-loaded wave guide for linear electron accelerators, R. B. R.-Shersby-Harvie (Atomic Energy Research Estab., Harwell, Eng.), *Nature* **162,** 890 (1948). A linear accelerator using a wave guide consisting of a metal tube lined with a dielectric appears to have practical advantages compared with a corrugated wave guide. Losses in the metal tube can be decreased by using an anisotropic dielectric with a smaller dielectric constant in the direction of the wave guide axis than in the transverse directions. This could be accomplished by using a stack of isotropic dielectric laminae in planes perpendicular to the wave-guide axis, with suitable spacers separating the laminae. The total losses for such a dielectric system compare favorably with those in a corrugated wave guide.

Range-energy and other relations for electrons in Kodak nuclear plates, M. A. S. Ross, B. Zajac (Univ. of Edinburgh, Scotland), *Nature* **162,** 923 (1948). Kodak type NTP2 plates, 30 μ in thickness, were exposed in a β-ray spectrograph using thorium and radium E to give continuous spectra. Electron tracks could be followed easily up to 50 kev, and with difficulty up to 80 kev energy, with the normal emulsion; with a more sensitive emulsion the longest track observed had an energy greater than 150 kev. Tables are given of mean energy of tracks vs mean range; grain density of track vs distance along the track; and mean energy of electrons vs stopping power of the emulsion.

Pulsating stars and nuclear energy, D. Stanley-Jones (Buckshead, Townshend, Hayle, Cornwall, Eng.), *Nature* **162,** 934 (1948). The phenomenon of pulsating stars is explained on the basis of a nuclear chain reaction. If the radiation pressure produced by a nuclear explosion in the interior of a star is great enough, it will reach the surface and carry away with it a halo of gaseous material. If the gravitational field and structure of the star are adequate to contain the explosion, the latter will be mostly confined to the boundaries of the star. After an expansion and increased luminosity, the gravitational forces will cause a collapse and the reaction will start again when the critical concentration of reactive materials is exceeded.

Interpretation of experiments on metabolic processes, using isotopic tracer elements, A. G. Ogston (Oxford Univ., Oxford, Eng.), *Nature* **162,** 963 (1948). An argument is given for the statement that the asymmetrical occurrence of isotope in a product cannot be taken as conclusive proof against its arising from a symmetrical precursor. It is possible that an asymmetric enzyme which attacks a symmetrical compound can distinguish between its identical groups.

Recording of charged particles of minimum ionizing power in photographic emulsions, R. W. Berriman (Kodak Research Labs., Harrow, Middlesex, Eng.), *Nature* **162,** 992–993 (1948). Photomicrographs are presented which give very strong evidence that an emulsion capable of recording the tracks of charges particles of any energy has been produced.

. . . I. W. RUDERMAN

LIFE SCIENCE PUBLICATIONS

Renal function in normal rabbits and dogs and the effect of uranyl salts, J. Wills, E. Main (School of Med. and Dent., Univ. of Rochester, N. Y.), *Am. J. Physiol.* **154,** 220–228 (1948). Uranyl salts cause a decreased reabsorption of chloride, decreased secretion of diodrast and probably an increased permeability of the tubular membrane to water and dissolved substances.

The rate of renewal in women of the water and sodium of the amniotic fluid as determined by tracer techniques, G. Vosburgh, L. Flexner, D. Cowie, L. Hellman, N. Proctor, W. Wilde (Dept. of Obstetrics, Johns Hopkins Univ. and Hosp., Baltimore, Md.), *Am. J. Obst. Gynecol.* **56,** 1156–1159 (1948). The water of the amniotic fluid is completely replaced every 2.9 hours on the average. The rate of transfer of water is five times greater than that of sodium.

Assimilation of tracer carbon in the alga scenedesmus, A. Brown, E. Fager, H. Gaffron (Biochemistry and Chemistry Dept., Univ. of Chicago, Ill.), *Arch. Biochem.* **19,** 407–428 (1948). A comparison of rate and total amount of light and dark fixation of labeled carbon dioxide and the properties of the resulting substances provides no evidence for the existence in significant quantities of a stable dark fixation product which may be identified as the precursor to the photochemical reduction of carbon dioxide. The dark fixation products isolated have either an indirect or no relation at all to photosynthesis.

Isotopic analysis of the oxygen evolved by illuminated chloroplasts in normal water and in water enriched with O^{18}, A. Holt, C. French (Dept. of Botany, Univ. of Minnesota, Minneapolis), *Arch. Biochem.* **19,** 429–435 (1948). It is believed that oxygen evolved by illuminated chloroplasts in the presence of various oxidants originates from the splitting of water molecules by a photochemical reaction.

Fixation of atmospheric carbon dioxide in the dark by leaves of bryophyllum, J. Thurlow, J. Bonner (Kerckhoff Lab. of Biology, California Inst. of Tech., Pasadena), *Arch. Biochem.* **19,** 509–511 (1948). Leaves of bryophyllum fixed atmospheric carbon dioxide in the dark when incubated at 2°–3° C for 60 hours.

Compounds related to dimethylthetin as sources of labile methyl groups, G. Maw, V. du Vigneaud (Biochemistry Dept., Cornell Univ. Medical College, New York), *J. Biol. Chem.* **176,** 1037–1045 (1948). Dimethylpropiothetin is a highly active methyl donor and an effective lipotropic and kidney antihemorrhagic agent. S-methylthioglycolic acid is unable to protect against kidney hemorrhagic damage and is unable to act as an efficient methyl donor to homocysteine. The S-methyl group was labeled with deuterium, and inappreciable amounts of this isotope were found in the methyl groups of tissue choline and creatinine after 11 days. The relationship of structure to methyl-donating ability is discussed.

The incorporation of acetate and butyrate carbon into rat liver glycogen by pathways other than carbon dioxide fixation, N. Lifson, V. Lorber, W. Sakami, H. Wood (Physiology Dept., Univ. of Minnesota, Minneapolis), *J. Biol. Chem.* **176,** 1263–1284 (1948). Following administration of carboxyl-labeled acetate or butyrate or beta carbon-labeled butyrate, all of the excess isotopic carbon in the glycogen of rat liver was found in positions 3 and 4 of the glucose unit. These are the same positions as for carbon dioxide fixation and since quantities of isotopic carbon were found in respiratory carbon dioxide it was impossible to determine from the location of the isotope in glycogen whether there was another pathway of conversion of fatty acid carbon to glycogen. All degradation fractions of glycogen contained excess isotope when either alpha carbon-labeled acetate, alpha and carboxyl carbon-labeled acetate or alpha carbon-labeled butyrate were fed, indicating that at least the alpha carbons of acetate and butyrate may enter glycogen by other than carbon dioxide fixation. The results after the administration of butyrate are consistent with the β-oxidation of butyrate to two moles of acetate but not to succinate.

Synthesis of carbonyl-labeled pyruvic acid, H. Anker (Biochemistry Dept., Univ. of Chicago, Ill.), *J. Biol. Chem.* **176,** 1333–1335 (1948). Starting with isotopic carbon dioxide and going through potassium acetate, acetyl bromide, acetyl cyanide and pyruvamide, labeled pyruvic acid was prepared in 40% over-all yield.

Some aspects of the metabolism of pyruvic acid in the intact animal, H. Anker (Biochemistry Dept., Univ. of Chicago, Ill.),

J. Biol. Chem. **176,** 1337–1352 (1948). Pyruvic acid is not in complete equilibrium with dietary carbohydrate. Pyruvic and acetic acid carbon atoms are incorporated into fatty acids.

On the metabolic fate of pyruvamide and acetamide, H. Anker, R. Raper (Biochemistry Dept., Univ. of Chicago, Ill.), *J. Biol. Chem.* **176,** 1353–1357 (1948). In the intact animal it is believed that pyruvamide is converted at a fast rate to acetic acid and formic acid. Pyruvamide may substitute for acetic acid in liver slices as a precursor for cholesterol and fatty acids. Acetamide is only slowly hydrolyzed to acetic acid.

Oxidation *in vivo* of emulsified radioactive trilaurin administered intravenously, P. Geyer, J. Chipman, F. Stare (Biological Chemistry Dept., Harvard Medical School, Boston), *J. Biol. Chem.* **176,** 1469–1470 (1948). Properly emulsified fat is utilized for energy immediately following intravenous injection.

2,6-Diaminopurine, a precursor of nucleic acid guanine, A. Bendich, G. Brown (Sloan-Kettering Institute for Cancer Research, N. Y.), *J. Biol. Chem.* **176,** 1471–1472 (1948). The compound was synthesized with isotopic nitrogen and administered to rats.

Blood volume determinations in the human with red cells containing radioactive phosphorus (P^{32}) and with pure human albumin, F. Kelly, D. Simonsen, R. Elman (Dept. Surg. and Med., Washington Univ. Med. School, St. Louis, Mo.), *J. Clin. Invest.* **27,** 795–804 (1948). Findings are in close agreement with those obtained by other investigators using similar and other methods.

The degradation of L-lysine in guinea pig liver homogenate. Formation of α-aminoadipic acid, H. Borsook, C. Deasy, A. Haagen-Smit, G. Keighley, P. Lowy (Kerckhoff Lab. of Biology, California Inst. of Tech., Pasadena), *J. Biol. Chem.* **176,** 1383–1393 (1948). α-aminoadipic acid is formed from L-lysine in guinea pig liver homogenates. Reaction is most rapid at *p*H of 7.5.

The degradation of α-aminoadipic acid in guinea pig liver homogenate, H. Borsook, C. Deasy, A. Haagen-Smit, G. Keighley, P. Lowy (Kerckhoff Lab. of Biology, California Inst. of Tech., Pasadena), *J. Biol. Chem.* **176,** 1395–1400 (1948). α-aminoadipic acid is converted to α-ketoadipic acid in guinea pig liver homogenate and the latter is oxidized to glutaric acid. The rate of deamination of α-aminoadipic acid is slower than its rate of formation from L-lysine. The rate of decarboxylation of α-ketoadipic acid is greater than the rate of deamination of α-aminoadipic acid.

Concerning the mechanism of the mammalian conversion of tryptophan to nicotinic acid, C. Heidelberger, E. Abraham, S. Lepkovsky (Chemistry Dept., Univ. of California, Berkeley), *J. Biol. Chem.* **176,** 1461–1462 (1948). Using D,L-tryptophan-3-C^{14} it is shown that the conversion to nicotinic acid proceeds in the same manner in the rat as in Neurospora. The carbon atom which is a precursor to the carboxyl group in hydroxyanthranilic acid becomes the carboxyl carbon of nicotinic acid.

Stripping film techniques for histological autoradiographs, G. Boyd, A. Williams (School of Med. and Dent., Univ. of Rochester, N. Y.), *Proc. Soc. Exptl. Biol. Med.* **69,** 225–232 (1948).

Secretion in cow's milk of intravenously injected radioactive phosphorus P^{32}, M. Kleiber, A. Smith, N. Ralston (College of Agriculture, Univ. of California, Davis) *Proc. Soc. Exptl. Biol. Med.* **69,** 354–356 (1948). A relative activity of 1.2% per liter of the injected dose was found in cow's milk five hours following injection. A week after injection this fell to 0.1% per liter. Radioactive casein was isolated from this milk. About 20% to 25% of the injected radioactive phosphorus was secreted in milk in the first week.

Thrombocytopenic purpura following therapeutic administration of radioactive sodium, H. Jacox (Columbia Coll. of Physicians and Surgeons, New York), *Radiology* **51,** 860–861 (1948).

Excretion of radium from the mouse, J. Weikel, E. Lorenz (U. S. Public Health Service, Bethesda, Md.), *Radiology* **51,** 865–870 (1948). An average of 19% of the radium remained in the mouse at death 100 to 240 days after injection. Average elimination rates agreed with results of other researchers. Radium was concentrated in the bone shortly after injection and was eliminated slowly. Soft tissue eliminated radium rapidly. Lungs contained very little radium. BAL (2,3-dimercaptopropanol) had no effect on the rate of elimination.

. . . BERNARD KANNER

PHYSICAL PUBLICATIONS

Berechnung eines spiral-bescleunigers fur schwere teilchen, W. Dallenbach, *Helv. Phys. Acta* **21,** 21–48 (1948). The design of a magnetic resonance spiral accelerator for heavy particles is discussed. Magnet design, including the amount of iron and copper needed, and cooling problems are treated. Curves are given for power dissipation in cases of 10, 100, and 1000-Mev accelerators. The radiofrequency electric field oscillators are also considered.

Einbittsresonanzen schneller neutronen an N^{14} und S^{32}, A. Stebler, P. Huber (Univ. of Basel, Switz.), *Helv. Phys. Acta* **21,** 59–86 (1948). Neutrons generated from the D-D reaction were directed on N^{14} and S^{32} targets. The resonances were determined using the products of (n,α) and (n,p) reactions.

Uber untersetzer, E. Baldinger, R. Casale (Univ. of Basel, Switz.), *Helv. Phys. Acta* **21,** 117–130 (1948). Various types of scaling units, their electronic characteristics, and resolving power are discussed. Transitron, multivibrator, and blocking oscillator circuits are included.

Herstellung und eigenschaften einer photographischen emulsion zum nachweis geladener teilchen, W. Halg, L. Jenny (Univ. of Basel, Switz.), *Helv. Phys. Acta* **21,** 131–136 (1948). The solutions used in making emulsions for alpha-particle and proton detection are described, and the range-energy relations for both particles in the emulsion are given.

Freinage des neutrons rapides dans le graphite, A. Houriet, A. Kind (Univ. of Geneva, Switz.), *Helv. Phys. Acta* **21,** 143–150 (1948). The slowing of fast neutrons in a graphite moderator was investigated theoretically assuming: a point isotropic source at the origin, an infinite moderator, and elastic collisions spherically symmetrical in the center of gravity system. The density and flux of neutrons as a function of position were calculated.

Measurement by radioactive tracers of diffusion in liquids, A. Gemant (The Detroit Edison Company, Detroit, Mich.), *J. Applied Phys.* **19,** 1160–1163 (1948). Diffusion coefficients in uranyl nitrate solutions, giving the diffusion of Th^{234} in water and dioxane, were measured with a Geiger counter registering the beta radiation of UX_2.

Cosmic-ray bursts at sea level and under thirty meters of clay, Chou Chang-Ning (Coll. of Science and Engineering, National Univ. of Amoy, China), *Phys. Rev.* **74,** 1659–1666 (1948). Ionization chambers of 1.15 liter volume were filled with argon to a pressure of 82 atmospheres and cosmic-ray bursts were registered with recording electrometers. Runs were made at the two stations with chambers unshielded and also with aluminum (to 33 cm) and lead (to 18 cm) above them. The bursts produced in lead at sea level up to medium thickness can be explained by the cascade theory for electrons and photons. The air-lead transition curves show a maximum at a greater lead thickness below sea level than at sea level.

Studies of bursts at sea level, H. Carmichael (Natl. Research Council, Chalk River, Ontario, Canada), *Phys. Rev.* **74,** 1667–1688 (1948). Bursts varying in intensity by a factor of 2,000 were measured in a variety of ion chambers of 175 and 1.1 liters, filled with argon, nitrogen and hydrogen from 1.5 to 87 atmospheres pressure. The results on unshielded ionization chambers indicate a clear separation into a component from the cascade showers of the atmosphere and another component from heavily ionizing particles emitted from nuclear disintegrations induced by cosmic rays. Assuming an energy spectrum for these protons and alpha particles so produced, the number-size distribution of the bursts from the second component was calculated, and agreement with experiment was obtained.

The lifetime of the heavy meson, J. R. Richardson (Univ. of California Los Angeles), *Phys. Rev.* **74,** 1720–1721 (1948). An experiment was performed to measure the loss of negative π-meson from a beam moving in a region of pressure 10^{-5} mm Hg, the assumption being that this loss corresponds to the $\pi \longrightarrow \mu$ decay process. The mesons produced in the 184-in. cyclotron were allowed to spiral in different orbits, the difference in the time of the detection (by photographic plate) corresponding to one revolution in the magnetic field. Only those mesons ending in stars were counted; their mass was in the region of 300 electron masses. Assuming a mass of 286, the time of one revolution is such that the half-life for this decay is

$$\left(7.7 \begin{array}{l} +2.1 \\ -1.5 \end{array}\right) \times 10^{-9} \text{ sec.}$$

On the relative abundance of the elements, R. A. Alpher, R. C. Herman (Johns Hopkins Univ., Silver Spring, Md.), *Phys. Rev.* **74,** 1737–1742 (1948). The theory of formation of the elements by neutron capture following production of protons by radioactive neutron decay has been modified by the explicit introduction of the expansion of the universe and the addition of neutron decay as a process competing with neutron capture. In the exact calculation, certain simplifications have been made. The observed relative abundance of the elements can be explained by a density of matter of 5×10^{-9} g/cm³ at the beginning of the capture process, which must have begun at a time that was short compared with the neutron lifetime.

Experimental determination of rate of energy loss for slow H^1, H^2, He^4, Li^6 nuclei in Au and Al, H. A. Wilcox (Univ. of Chicago, Ill.), *Phys. Rev.* **47,** 1743–1745 (1948). A particle source is described which consists of a Cockcroft-Walton accelerator with a magnetic beam selector. The charge collects on a target from which either scattered particles or particles from a reaction provide a monoenergetic beam. For following passage through the Au or Al foil, an energy analyzer (electrostatic) and electron multiplier are used to measure the energy losses. The particle energies range from 30–1,400 kev. Integrated range-energy curves are given. The slight discrepancy between energy losses for protons and deuterons of the same velocity is explained.

Search for photons from meson-capture, O. Piccioni (Massachusetts Inst. of Technology, Cambridge), *Phys. Rev.* **74,** 1754–1758 (1948). A telescope was used to focus mesons which were then directed through a lead absorber onto an iron block. A counting setup is described that registers the path of any ionizing particle emerging in a direction roughly perpendicular to that of mesons which are stopped in the iron (as shown by coincidence circuits). The results indicate that no high-energy (50 Mev) photons arise from capture of negative or free decay of positive mesons.

Variational methods in nuclear collision problems, W. Kohn (Harvard Univ., Cambridge, Mass.), *Phys. Rev.* **74,** 1763–1772 (1948). The use of trial functions with undetermined coefficients in a variational method is extended to the phase shifts and elements of the scattering matrix for nuclear collisions. Neutron-proton and neutron-deuteron scattering are considered as examples.

On the virtual excited state of the Be⁹ nucleus, C. Longmire (Univ. of Rochester, N. Y.), *Phys. Rev.* **74,** 1773–1775 (1948). The very low binding energy of the last neutron in Be^9 suggests as a model the motion of that neutron in a potential well provided by the rest of the nuclear particles. The radius and depth are related by the 1.63 Mev binding, assuming a reasonable radius gives no other bound states. An examination of the virtual states of this system in regard to proper energy and width gives the lowest D state as a loose interpretation of the observed virtual excited state 2.41 Mev above the ground state (on this model). Calculations are made on the angular distribution of inelastically scattered protons from the virtual level.

Tc^{92} and Tc^{93} by relative cross-section measurements, D. N. Kundu, M. L. Pool (Ohio State Univ., Columbus), *Phys. Rev.* **74,** 1775–1781 (1948). Deuteron bombardment of natural and enriched Mo isotopes assign 2.7-hr. 47-min, and 4.5-min half-lives to production from Mo^{92}. The relative cross sections found for production of these activities compared with the results of the ratio for p,n and p,γ reactions from Mo^{95}. The 47-min activity is assigned to Tc^{92}, the others to Tc^{93}. The radiations of each isotope are described.

Energy straggling of protons, C. B. Madsen, P. Venkateswarlu (Univ. of Copenhagen, Denmark), *Phys. Rev.* **74,** 1782–1784 (1948). The strong resonances of Al and F at 986 and 339 kev, respectively, were used as energy indicators (the gamma rays were counted) for proton beams. The standard deviations of the energies of the beams were measured before and after transmission through thin foils of beryllium and mica of various thickness. The mica thicknesses were measured with an interferometer. The straggling so measured agreed well with theory as a function of thickness and mass and atomic number of the scatterer.

On the theory of the recoil in β-decay, O. Kofoed-Hansen (Univ. of Copenhagen, Denmark), *Phys. Rev.* **74,** 1785–1788 (1948). The recoil spectrum is derived for beta decay on the basis of the Fermi theory with various couplings between nucleons and light particles, for allowed and first forbidden transitions. Where

gamma rays are emitted following the beta disintegration, the average recoil energy is independent of possible angular correlation. The change in the recoil spectrum, if the neutrino has a finite rest mass, and the influence of the kinetic energy of the recoil are discussed.

Deuteron and triton methods, W. Rarita (Brooklyn College, N. Y.), *Phys. Rev.* **74,** 1799–1801 (1948). Matching the known radial S and D wave functions outside the nucleus to the wave function inside, as expanded in modes, and using the variational principle, almost all of the binding energy can be accounted for. Using the square well, the joining condition was relaxed. The depths corresponding for the exponential and meson potentials were calculated. The triton binding energy was calculated with and without tensor forces.

Scattering of particles in air showers, L. Eyges (Cornell Univ., Ithaca, N. Y.), *Phys. Rev.* **74,** 1801–1806 (1948). The distribution function for singly scattered electrons was calculated without using the Arley approximation (which neglects radiation processes below the critical energy). The probability that a singly scattered particle can be found in the annular ring between x' and $x' + dx'$ is $0.16dx'/x'^3$, where x' is the Moliere unit. The most important process contributing to the electrons at large distances is radiation and rematerialization of electrons below the critical energy.

Starting potential of the Geiger-Müller counter discharge, P. B. Weisz (Socony-Vacuum Labs, Research Dept., Paulsboro, N. J.), *Phys. Rev.* **74,** 1807–1812 (1948). A study was made of the starting potential (where pulse equalization sets in) in Geiger-Müller counters as a function of the composition of the counting gases (argon and helium mixed with various hydrocarbons). The results were interpreted using the known electronic energy levels of the hydrocarbon series to explain the production of ions in the initiating process.

The heavy component of primary cosmic rays, P. Freier, E. J. Lofgren, E. P. Ney, F. Oppenheimer (Univ. of Minnesota, Minneapolis), *Phys. Rev.* **74,** 1818–1827 (1948). Tracks in photographic emulsions exposed at about 90,000 ft indicate the existence of heavy nuclei (up to $Z = 41$) as a component of the primary cosmic radiation. The Z values of these nuclei were estimated by means of the knock-on electrons which they produce and the decrease of track thickness near the end as they capture electrons. The regular increase of average energy with atomic number indicates that they were accelerated as stripped nuclei by the same mechanism as the primary protons. The mean free path for nuclear collisions was longer than that expected from geometrical cross sections, indicating a possible velocity dependence of nuclear forces. Cloud-chamber pictures gave a ratio of hydrogen to helium (protons to alphas) of four, as in the sun.

Investigation of the primary cosmic radiation with nuclear photographic emulsions, H. L. Bradt, B. Peters (Univ. of Rochester, N. Y.), *Phys. Rev.* **74,** 1828–1837 (1948). Determination of charge Z and energy E of the heavy primaries of cosmic radiation can be made by investigating range and specific energy loss (grain density) in photographic emulsions, or from range and delta-ray density measurements. Such measurements have shown atomic numbers up to 30 in the primaries. A nuclear explosion caused by collision with a silver nucleus of a heavy primary is described. Both the magnitude of the flux and the distribution of heavy primaries give information on the origin of cosmic radiation; the necessary primary proton energies (not to be stopped by the earth's magnetic field) preclude their detection in plates.

On the energy of cosmic radiation allowed by the earth's magnetic field, M. S. Vallarta (Univ. of Mexico, Mexico, D. F.), *Phys. Rev.* **74,** 1837–1840 (1948). The proton energies allowed by the earth's magnetic field in the vertical direction are given as a function of geomagnetic latitude, as are those in the directions 45° east, west, north, and south. Distance and angular corrections due to the longitude effect are given for various geographic latitudes.

The absorption of gamma-radiation, C. L. Cowan (Washington Univ., St. Louis, Mo.), *Phys. Rev.* **74,** 1841–1845 (1948). Using various radioisotopes as a source of gamma rays of various energies, and a Geiger counter as a detector, the absorption coefficients of elements of different Z were measured. The geometry used was such that the absorbers could intercept all detected gamma-rays. The whole apparatus was suspended outdoors 25 feet above the ground so as to reduce scattering. The absorption coefficients

are plotted for different elements as a function of energy of the gamma radiation and agree very well with theory.

The alpha-ray spectrum of polonium, W. G. Wadey (Univ. of Michigan, Ann Arbor), *Phys. Rev.* **74,** 1846–1853 (1948). Alpha-ray spectra of polonium mounted on silver, cadmium, and nickel backings were investigated with a semicircular focusing spectrometer, using photographic plates for detectors. The weak line series previously reported was not found. The mounting metal had a strong influence on the spectrum obtained. It is proposed that, with the exception of the 5.3-Mev line, all the observed spectra are due to diffusion of the polonium into the metallic mounting, where it is segregated if the mounting has a crystal structure to give an apparent line structure.

Statistical error in absorption experiments, M. E. Rose, M. M. Shapiro (Oak Ridge Natl. Lab., Tenn.), *Phys. Rev.* **74,** 1853–1864 (1948). The problem of achieving minimum statistical error in a given counting time or the minimum counting time for a given accuracy is investigated for such absorption experiments as the measurement of cross sections by transmission. The geometry for optimum transmission and best division of counting times among transmitted and incident beams and background were investigated for backgrounds from 10^{-3} to 10^{2} (relative) as follows: with beam area fixed and absorber thickness varied, and with both beam area and absorber thickness variable but total amount of absorber fixed. Optimum transmission curves and curves giving the fractions of counting time as a function of relative background are given.

Neutrons in the penetrating showers of cosmic radiation, G. Cocconi, V. Cocconi-Tongiorgi, K. Greisen (Cornell Univ., Ithaca, N. Y.), *Phys. Rev.* **74,** 1867–1868 (1948). An anticoincidence circuit detected local penetrating showers produced in lead blocks at 3,200 meters above sea level. A neutron detector consisting of proportional counters imbedded in a large paraffin block was used. It was concluded that many of the neutrons of moderate energies come from evaporation of excited nuclei, both those from which the penetrating particles come and nearby nuclei excited by particles produced in the primary act. Heavy ionizing particles (appearing as stars) are probably also evaporated by the excited nuclei.

β-disintegration and the Sargent diagram, N. Feather, H. O. W. Richardson (Univ. of Edinburgh, Scotland), *Proc. Phys. Soc.* **61,** 452–466 (1948). Sargent diagrams for heavy ($80 < Z < 94$) and light ($Z < 22$) emitters of electrons and positrons are discussed in the light of various forms of interaction in the Fermi theory. The heavy elements have groups corresponding to allowed, first-forbidden, and second-forbidden transitions on the basis of parity and spin changes. Some of the transitions in heavy nuclei are to excited states. The lightest elements appear to have, in addition, a "super-allowed" group of transitions (from ground to ground state) not necessarily forbidden by any rules. These usually are positron activities.

Coincidence experiments using a permanent magnet double β-ray spectrograph with coincidence counting—I. Experiments with thorium active deposit, N. Feather, J. Kyles, R. W. Pringle (Univ. of Edinburgh, Scotland), *Proc. Phys. Soc.* **61,** 466–477 (1948). A semicircular spectrometer focuses two pencils of electrons which emerge from a thin source in opposite directions. The two groups are separately analyzed with two counters connected in coincidence; the counters are movable so that the energy of the measured electrons may be varied. The coincidences between a conversion line and the continuous β-spectrum correlates portions of the continuous spectrum with emitted γ-rays. This was done for various groups in ThB, ThC, and ThC′, and the conversion coefficient for the *F*-line of ThB was found to be 0.288.

An investigation of the neutrons produced in the deuteron-deuteron reaction, D. L. Livesey, D. H. Wilkinson (Cambridge Univ., Cambridge, Eng.), *Proc. Roy. Soc.* **A195,** 123–134 (1948). The reaction $D(D,n)He^3$ was investigated using a thick heavy phosphoric acid target bombarded with a 0.92-Mev deuteron beam. Photographic plates were used to detect the proton tracks produced by elastic scattering of the emitted neutrons. The Q value was found to be (3.23 ± 0.02) Mev. The angular distribution of neutrons and their energy spectrum at a given angle was investigated. The spectra agree well with those calculated on the basis of the excitation function for total yield, when straggling effects are considered. The angular distribution shows a maximum at 0° and a minimum at 90° to the deuteron beam.

Some properties of BF_3 in ionization chambers, J. A. Bistline, Jr. (Cornell Univ., Ithaca, N. Y.), *Rev. Sci. Instr.* **19,** 842–846 (1948). The pulses produced by alpha-particle ionization in BF_3 ionization chambers were investigated to determine the properties of electron collection in BF_3. About $\frac{1}{3}$ as much energy is required to produce an ion pair in BF_3 as in argon, as shown by comparison of pulse heights. The mean drift distance of an electron before capture is given as a function of the voltage gradient divided by the gas pressure. The drift velocity was also found over a wide range of this parameter.

A microwave gas discharge counter for the detection of ionizing radiation, S. C. Brown, J. J. McCarthy (Massachusetts Inst. of Technology, Cambridge), *Rev. Sci. Instr.* **19,** 851–860 (1948). A 3,000-Mc electric field acting on a gas causes a discharge when an ionizing particle enters the cavity. Since the discharge is independent of secondary effects, a pulse rise time of 10^{-8} sec is available for this type of counter, with two microseconds resolving time. This is an order of magnitude better than d-c discharge of a Geiger counter. The characteristics of a gamma-ray counter utilizing this principle are described, including the effect of a clearing field (d-c) and quenching agent. Sensitivity and plateau characteristics are similar to those of a Geiger counter.

The electron multiplier as a counter for 10-kev protons, J. M. Robson (Natl. Research Council, Chalk River, Ont. Canada), *Rev. Sci. Instr.* **19,** 865–871 (1948). As an aid in detecting the protons resulting from radioactive decay of neutrons a counter is needed which will count low-energy protons without use of a counting gas or window. An electron multiplier of the Allen type has been found to give, using 14 beryllium-copper electrodes, 80%–100% efficiency for protons in the energy region 5–10 kev. Bias curves indicate a pulse height of about 20 millivolts. The multiplier was checked with alpha particles and gamma rays.

The production of intense ion beams in a mass spectrometer, R. H. Bernas, A. O. C. Nier (Univ. of Minnesota, Minneapolis), *Rev. Sci. Instr.* **19,** 895–899 (1948). A 60° mass spectrometer has been built which uses very intense ion beams. The beam is produced by directing a magnetically collimated electron beam onto the vapor issuing from a furnace. With an accelerating voltage of 15 kv, total ion currents of 1–2 ma were obtainable; a total current of as much as 0.3 ma for individual isotopes at the collector was observed. Resolving power $\frac{1}{100}$ was obtained.

High voltage pulser for 184-inch cyclotron electric deflector, Q. A. Kerns, W. R. Baker, R. F. Edwards, G. M. Farly (Univ. of California, Berkeley), *Rev. Sci. Instr.* **19,** 899–904 (1948). A pair of symmetrically connected 100-kv pulse transformers are used to generate the pulse required to deflect the beam of the 184-in. California synchrocyclotron. Pulse capacitors are discharged through the primary windings by triggering thyratrons, output voltages being developed across the 17-turn secondary winding. The deflecting potential developed is 200 kv, and rises from 10% to 90% of peak value in 0.1 microsecond.

High frequency proton source, R. N. Hall (California Inst. of Technology, Pasadena), *Rev. Sci. Instr.* **19,** 905–910 (1948). The construction and performance of a proton source for an electrostatic accelerator employing a high-frequency electrodeless discharge as the ionizing agent is described. The frequency is 450 Mc/sec, and a magnetic field is employed. Ion currents of 400 microamperes are obtained; the current density of focused, analyzed protons is 0.03 amp/cm² at the exit hole. The hydrogen flow of the source is 30 cc/hr; the gas is kept from the accelerating column by differential pumping.

A study of small ether-argon Geiger-Müller counters, C. V. Robinson, R. E. Peterson (Univ. of Wisconsin, Madison), *Rev. Sci. Instr.* **19,** 911–914 (1948). Various mixtures of ether and argon were used in counters whose central wires varied from 0.5 to 2.3 mils, and whose cathodes varied from 38 to 268 mils in diameter. Construction of the counters is described, and the results on plateaus given, along with life tests. There appears to be an optimum relationship among mixture, cathode and wire diameters. Good counters were obtained with cathodes as small as $\frac{1}{16}$ in. in diameter. Small probing counters designed on this basis are described.

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